A Platform for Antenna Optimization with Numerical Electromagnetics Code Incorporated with Genetic Algorithms

THESIS

Timothy L. Pitzer, Second Lieutenant, USAF

AFIT/GE/ENG/06-46

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GE/ENG/06-46

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Timothy L. Pitzer, B.S.E.E.

Second Lieutenant, USAF

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Timothy L. Pitzer, B.S.E.E.

Second Lieutenant, USAF

Approved:

/signed/	3 Mar 2006
Dr. Andrew J. Terzuoli (Chairman)	date
/signed/	3 Mar 2006
Dr. Gary B. Lamont (Member)	date
/signed/	3 Mar 2006
Lt Col James A. Fellows, PhD (Member)	date

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Abstract

This thesis investigation presents a unique incorporation of the Method of Moments with a Genetic Algorithm. The use of this tool can improve antennas whose basis of designs are both the Yagi-Uda antenna and the Log Periodic Dipole Array (LPDA) antenna. The applications for these two antennas are of particular use in Passive Remote Sensing (PRS) and Over the Horizon Radar (OTHR). The designs are reached in a low cost and effective manner, the implementation of which is simple and expandable.

A Genetic Algorithm (GA) is used in concert with the Numerical Electromagnetics Code, Version 4 (NEC4) to create and optimize typical wire antenna designs including single elements and arrays, the result being antennas with impressive characteristics.

Previous work in antenna optimization is documented and discussed as it relates to the current research. Design parameters for the antenna are defined and encoded into a chromosome composed of a series of numbers; the effects of changing said chromosome are likened to that of natural selection. The cost function associated with the specific antenna of interest is what quantifies improvement and, eventually, optimization. This cost function is created and used by the GA to evaluate the performance of a population of designs. The most successful designs of each generation are kept and altered through crossover and mutation. Through the course of generations, convergence upon a *best* design is attained. As an example, two antennas have been focused on and improved: a Yagi-Uda antenna and a Log Periodic Dipole Array (LPDA) antenna.

The objectives for each antenna are to maximize the main power gain while minimizing the Voltage Standing Wave Ratio (VSWR) and the antenna's length. Results in the Yagi-Uda exceed previous designs by as much as 40 dB while maintaining

respectable length and VSWR values. The improvements made in the LPDA were not as drastic, finding a nominal increase in power gain while truncating original allowance in the length by more than half, along with nominal VSWR values that were close to the ideal value of one. The percentage of bandwidth covered for the frequencies of interest are 8.11% for the Yagi-Uda and 10.7% for the LPDA.

GA performance is evaluated and, based on previous results, implemented with real-numbered chromosomes as opposed to the classic binary encoding. This methodology is very robust and is improved upon in this research, all while using a novel approach with an optimization program platform called iSIGHT, developed by Engineous Software. This platform is well documented and exampled to aid in its future use for similar applications.

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This work is the direct result of the support I received from my wife, my family, my friends, and the very knowledgeable professors on my thesis committee. To each of them I give my thanks and without each of their personal contributions, this thesis would be lacking in particular ways.

My wife foremost deserves credit, almost to the extent of dual authorship. It is by her grace and encouragement that I was able to focus on my studies and research with success. She is a daily reminder of the grace that Christ, my Savior, has given me and it is through our marriage I've learned even better that grace and how I am so undeserving. Her love for me is a driving force.

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To Dr. Andrew Terzuoli, Dr. Gary Lamont, and Lt Col James Fellows, I extend my appreciation. They are the committee that I would choose time and time again. They have been professional and have pushed me hard while allowing me to see the big picture of what I am doing in my research. They have the perfect touch of condemning in the same moment of praise. My thanks to each of them.

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My body may belong to the Air Force but my heart will remain ever true to my God and Savior. Jesus Christ is the greatest thing that has ever come into my life. The free grace that He gives to me allows me to call Him "Father." I will always sing

His praise and to Him alone will I look for recognition, acceptance, and salvation. Praise be to His name forever.

Timothy L. Pitzer

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A Platform for Antenna Optimization with Numerical Electromagnetics Code Incorporated with Genetic Algorithms

I. Introduction

Optimization with genetic algorithms has not only become more widespread within the electromagnetic community, its realization has become more realistic with the evolution of powerful computers and computer programs. In addition to technical knowledge, intuition is required for an efficient and effective antenna design, although, until recently, intuition has been difficult to apply in automated processes due to the lack of available tools. In lieu of intuition, genetic algorithms can define and search a large design space, resulting in an unintuitive and yet very effective antenna product. Defining and approaching this problem may be done by focusing on particular characteristics of the antenna, evaluating synthesized designs, and using improvements to complement further antenna synthesis.

1.1 Problem Domain and Approach

Current Over the Horizon Radar (OTHR) and Passive Remote Sensing (PRS) antennas have room for improvement in their main lobe gain, Voltage Standing Wave Ratio (VSWR), and the size of the antenna structure. Improvements in these areas lead to the greater rejection of unwanted signals as well as implementation of the product in a smaller, more convenient space. For some applications, these antennas need to fit in spaces much smaller than the largest wavelength associated with the frequencies of interest. The desired frequency bandwidth here is 3 MHz to 30 MHz and the wavelength of the lower frequency is approximately 100 meters. This great length usually requires large antenna structures that are impractical for smaller areas. The method for reducing the size of the antenna as well as the maintenance or improvement of the antenna characteristics is explained.

Optimization with GAs has not only become more widespread within the electromagnetic community, its realization has become more realistic with the evolution of powerful computers and computer programs. In addition to technical knowledge, intuition is required for an efficient and effective antenna design. Until recently, intuition has been difficult to apply in automated processes due to the lack of available tools. In lieu of intuition, GAs can define and search a large design space, resulting in an unintuitive and yet very effective antenna product.

The purpose of the Log Periodic Dipole Array (LPDA) and Yagi-Uda experimental design is to both minimize antenna structure size and maximize the power gain for that antenna, all while reducing the VSWR. In this study, a GA integrated with the Numerical Electromagnetics Code, Version Four (NEC4), the result being antennas with impressive characteristics. This code is the most current of the NEC codes and includes more geometry and control commands than previously available in versions two and three. It also provides ASCII output documents that are consistent, an integral part of incorporating a program into a genetic algorithm. iSIGHT [16] is the optimization program used which implements a Non-dominated Sorting Genetic Algorithm - NSGA II. The use of iSIGHT makes this study a novel approach in antenna modeling. It allows a unique interface to GAs and antenna design. Graphical Numerical Electromagnetics Code (GNEC) [44] is the graphical interface program from which NEC4 is called. GNEC is a natural choice in modeling antennas because of its robustness and wide use in the electromagnetic community. Additionally, it may be implemented with great ease with products such as NEC-Win Plus+ [44] though this study creates all antenna designs with a DOS Batch script employing *dnec4dma.exe*, the executable for NEC4.

Passive sensing is achieved through signals of opportunity such as the transmission of television or radio waves. The reflection of these signals off targets are collected in a bistatic manner and the devices for this are implemented inexpensively. Research is still underway for improving this technique. Reducing sidelobes and backlobes for

this application is particularly useful for focusing on the reflections from the target instead of the source of the electromagnetic waves.

With a developed OTHR system, tracking uncooperative targets such as the planes involved in the September 11th terrorist attack would be possible and accurate to within 15 miles. The United States Air Force (USAF) Air Force Research Laboratory (AFRL) Sensors Directorate (SNR) is actively researching OTHR systems and the antennas that would be implemented in such a system. Included in the objectives of this research are both to decrease the size required for the LPDA array as well as to increase its main lobe power gain performance.

1.2 Research Design

In this section, previous work in antenna optimization is documented and discussed as it relates to the current research. Design parameters for the antenna are defined and encoded into a chromosome composed of a series of numbers; the effects of changing said chromosome are likened to that of natural selection. The cost function associated with the specific antenna of interest is what quantifies improvement and optimization. This cost function is created and used by the GA to evaluate the performance of a population of designs. The most successful designs of each generation are kept and altered through crossover and mutation. Through the course of generations, convergence upon a *best* design is attained. The objectives are to maximize the main power gain while minimizing the VSWR and the antenna's length. GA performance is evaluated and, based on previous results [41], implemented with real-numbered chromosomes as opposed to the classic binary encoding.

In this research, it is assumed that better antennas can be designed for particular applications. It is also assumed that a design space for a specific antenna can be defined and searched for the particular antennas whose characteristics are improvements when compared to previous designs. Constraints on design are in the amount of elements in each antenna, the length of those elements, and the overall length of

the antenna structure. These constraints vary for each antenna and are declared in Chapter III.

This methodology is very robust and is improved upon in this research all while using a novel approach with an optimization program platform called iSIGHT, developed by Engineous Software [16]. This platform is well documented and exampled to aid in its future use for similar applications.

A diagram of the process implemented in this research for designing antennas is shown in Figure 1.1. This flow chart must start with an antenna design created by the user and then, by working within constraints and while improving upon objectives, creates new antenna input files with the aid of the program iSIGHT. This new antenna file is executed by NEC4, the results from that run are compared to previous antenna performances, and the process repeats.

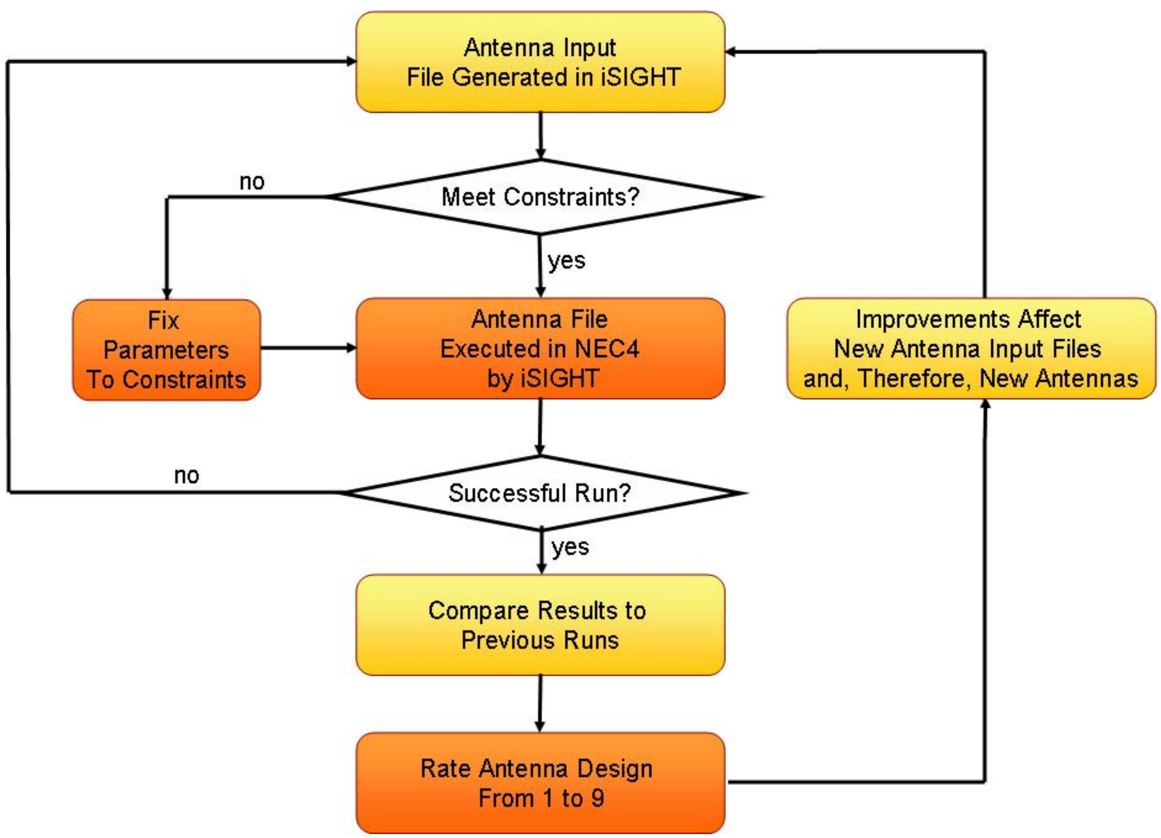


Figure 1.1: A flow chart diagraming the process of antenna design with genetic algorithms

1.3 Assumption of Readership

It is assumed in this research that the reader has a background in both electromagnetics and evolutionary algorithms. Specifically, how electromagnetics may be used to describe antennas in the far-field and how algorithms may be developed to synthesize structural designs based on defined objectives and the performance of previous structural designs with regard to those objectives.

1.4 The Goals and Objectives of this Research

The primary goal in this research is to develop a computational process inside a reproducible package that improves antenna design with the use of genetic algorithms. The efforts towards this development are supported by the potential gain in implementing the results. Antennas play a critical step in the Radio Detection and Ranging (RADAR) chain of signal processing. As an important step in signal processing, it is important that antennas are well designed for particular applications. The particular applications focused on in this research are only a few of the many applications where there is still much room for improvement. Any improvement in antenna performance, even small improvements, can play crucial roles in detecting targets with small Radar Cross Section (RCS) signals.

In this research the computational process and package is well-documented such that applying the methodology herein to future antenna design projects may be done with ease. The computational process is then validated by improving upon an existing Yagi-Uda antenna design found in [41]. After improving upon this antenna design, the method is applied to a LPDA and conclusions are drawn from the results.

1.5 Thesis Outline

This thesis presents a background on work done in antenna optimization through the use of genetic algorithms. This is seen in Chapter II as well as the various antennas considered for optimization in this research. Three algorithms are described and, in

Chapter III, one is chosen based on merit for and compatibility with the research. In Chapter III, two antenna structures are chosen for antenna improvement, the Yagi-Uda and the LPDA. This is done through the process of antenna design and synthesis that is described in Chapter III. The results of using the computational package with the Yagi-Uda and LPDA are documented in Chapter IV and conclusions are made in Chapter V. Also in Chapter V are suggestions for future work in antenna optimization.

The culmination of this research, reached through the studies documented in Chapter II, educates the reader on a reproducible approach to antenna synthesis and analyses with GAs, an area whose surface is still only scratched.

II. Background in Antenna Design and Optimization with Genetic Algorithms

Research in antenna optimization with the use of GAs has progressed from the theoretical into implemented research in the early 1990s [40]. The discussion in this chapter develops the background of both antennas and genetic algorithms and explores the progress made both in optimizing basic antenna configurations and the process of analyzing the results from these antenna designs. The USAF AFRL/SNR is actively pursuing this area of research. Development of optimized antennas for High Frequency OTHR and PRS are two applications that follow naturally from this and are developed and further evaluated in Chapter III by building on the work in antenna optimization and genetic algorithms documented in this chapter.

2.1 Over the Horizon Radar

OTHR has progressed from its earliest use by military personnel only to techniques available to the common hobbyist. It retains military application but still has indefinite potential for improvement. OTHR has applications whose precision depends on prediction of atmospheric bounce, prediction of holes created by these bounces, and prediction of their nulls. Predictions of ionospheric conditions are vital to predicting the scattering pattern. Future work in these areas and development of a methodology for that ionospheric prediction would prove applicable to various radar applications.

The frequency bandwidth associated with High Frequency (HF) OTHR is from 3 MHz to 30 MHz [50]. The electric fields at these frequencies can propagate over large distances, over the horizon, due to their large wavelength and thus their ability to reflect off both the ionosphere and the ground. Unlike higher frequencies whose fields penetrate the ionosphere, HF frequencies propagate over extremely large distances by scattering from objects upon incidence. The variance in both the density and the altitude of the ionosphere prevents accurate prediction of how far the wave has traveled once reception of scattered signals is received. These two variables have prevented

precise results from OTHR until the recent advances in ionospheric modeling but there is still great room for improved accuracy. Prediction of ionospheric scattering would be very helpful in optimizing OTH radars though, as stated earlier, the area is still under-developed.

Dish arrangements as well as antenna array configurations are the most common in OTHR. Antenna array configurations are by far the most common and the concentration of development in the past 20 years, though systems using the dish arrangement developed prior are still in use.

2.2 Passive Remote Sensing

Passive Remote Sensing (PRS) is a bistatic form of radar detection whose principal advantages are cost, functionality, and the ease with which the platform can be relocated. The principal power cost of transmitting and receiving in radar is that of producing a radio signal powerful enough to detect at twice the distance between the radar and the target of interest. In PRS, instead of producing a powerful transmitted signal, the application takes advantage of powerful signals that already exist. Bistatic radar functions compared to monostatic radar functions have inherent capabilities that are of extreme advantage. When considering the design of stealth aircraft, which are largely shaped to reduce the RCS signature in a monostatic case, the ability to track the target via other than forward and back scatter greatly improves the probability of detection. This design in stealth aircraft is more effective against the monostatic detector which is not able to detect electric fields scattering off the side of the aircraft. Since the signal is not transmitted from the point of detection in bistatic radar, the effectiveness is increased and the size of the receiving platform can be greatly decreased and made more feasible to relocate.

In [22], passive detection at ranges greater than 150 km in real time, using simple computer hardware, a dipole antenna, and a single FM radio for signal transmission is achieved. Earlier work in this area lays out the process through which bistatic radar becomes possible with the use of television-based wave transmissions [23].

2.3 Genetic Algorithm Optimization

A genetic algorithm is a "robust stochastic search technique that mimics the process of natural selection by operating on a population of possible solutions" [18]. There are two approaches to solutions in genetic algorithms: real value solutions, and binary solutions. In real value solutions the GA iterates until a predefined numerical precision is reached within the solution. Binary solutions turn parameters either on or off. When applied to a grid space, the GA either adds or subtracts material in a binary fashion. The end result is as precise as that of the grid size. An example of this process is seen in Figures 2.1 and 2.2 [1].

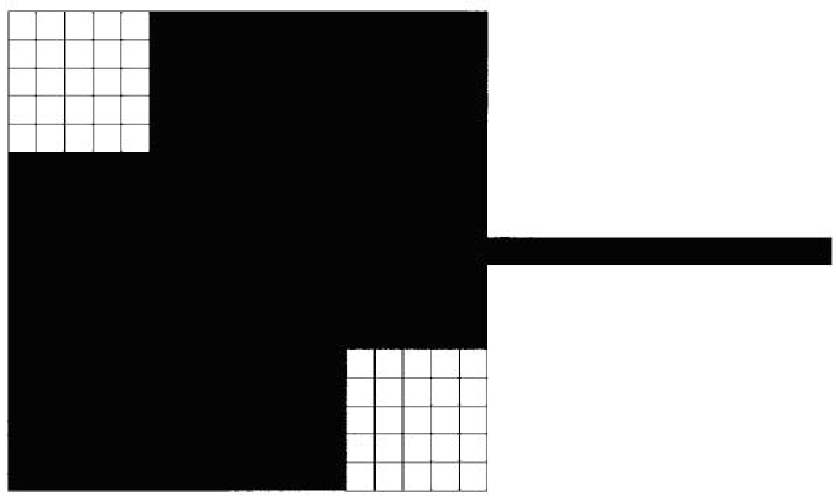


Figure 2.1: Patch antenna with grid structure [1]

Depending on the goals of the optimization, single objective or multi-objective approaches can be used to attain the desired antenna characteristics. Single objective optimization optimizes only one parameter. This approach is excellent for simple problems where changing one parameter can produce the preferred results. Multi-objective optimization is more rigorous in solution and covers more difficult problems but the iteration time on a computer is greatly increased. In the example of a two parameter optimization, each with N possible solutions, the run time will be much longer since N^2 possible solutions must be considered as opposed to the former N solutions.

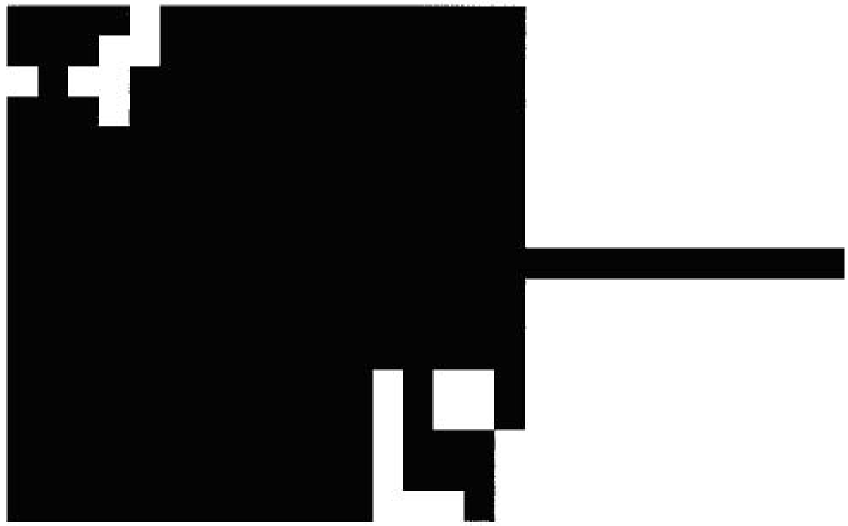


Figure 2.2: Optimized patch antenna using binary approach [1]

Iterations for GAs must be developed for each specific problem. This process starts with a parent structure; child structures are then developed from the parent [26]. Figure 2.3 illustrates a combination which comes from two parents whose last five values are alternated for each child's development.

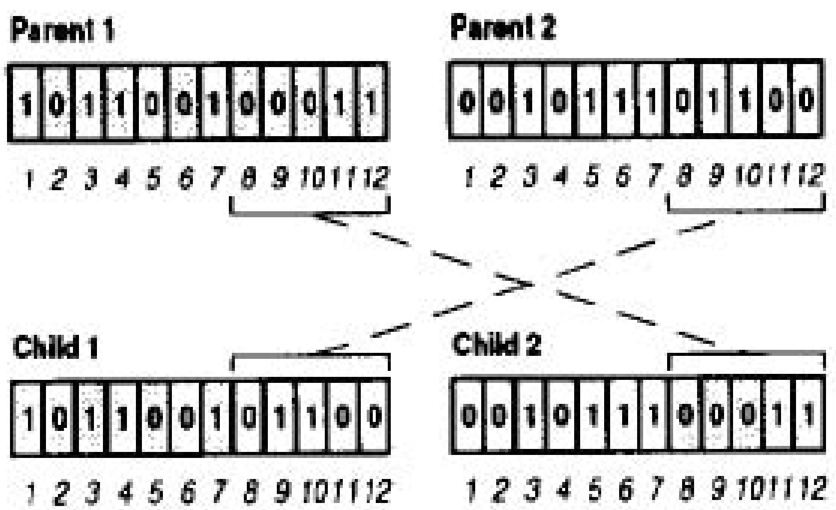


Figure 2.3: An example of cross-over with a length ν=12 chromosomes [25]

Another variation of chromosome changes can be seen in Figure 2.4 where there is a single parent whose structure is altered to give way to the child. This mutation

operator has chosen the fourth value to alter. Combinations of these operations produce the varied parameter set that develops each proposed antenna solution and then analyzes for merit within the given problem.

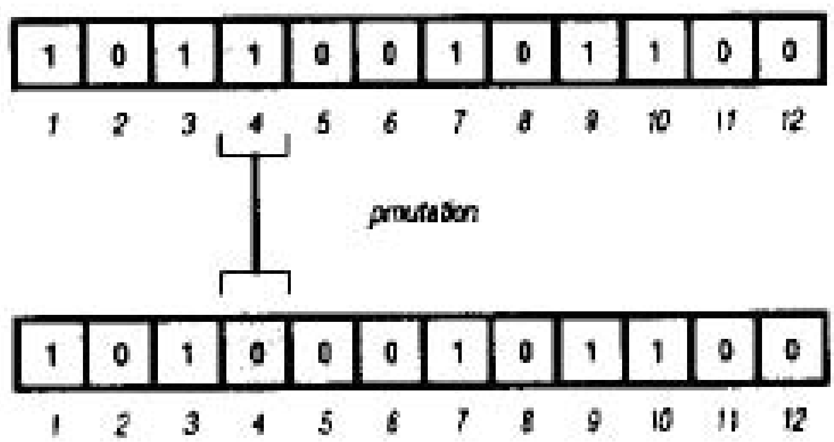


Figure 2.4: An example of the action of the mutation operator [25]

GAs can be applied to a variety of antenna applications. Wire antennas in particular have been the concentration of many literature compositions [12, 30, 38, 39, 49, 53]. Van Veldhuizen et. al. [53] improved the geometries of wire antennas using GAs and NEC (Numerical Electromagnetics Code) under "user-defined adverse conditions." In that literature they specify that NEC was used to test "fitness of promising designs" once they had been iterated by the GA.

GAs can also vary widely in applicability to particular problems. Two are used and then compared in [12] by Caswell and Lamont wherein examination of the relative advantages of each are evaluated using the experimental results. This variance between different GAs is expected due to the wide variety of approaches along with the GA's ability to iteratively solve the given conditions.

This methodology may also be found in [12, 40, 53] and efforts to improve upon a resulting antenna from [40] are found in [41]. That research focuses on Yagi-Uda antenna design.

Whereas a single objective approach eases computation time and simplifies the cost function associated with the project, a multi-objective algorithm is used so as to find the *best* combination where improving upon one facet is impossible without diminishing the improvement of another facet. The specifics for that algorithm are as follows.

2.4 Genetic Algorithms Inside iSIGHT

Three genetic algorithms are considered in developing the methodology for synthesizing new antennas. They are the three GAs that are incorporated into iSIGHT and are as follows:

- Multi-Island Genetic Algorithm - (MIGA) [16]
- Neighborhood Cultivation Genetic Algorithm - (NCGA) [16]
- Non-dominated Sorting Genetic Algorithm - (NSGA-II) [16]

The common features for each of these genetic algorithms is that each design point is perceived as an individual with a certain value of fitness based on the value of objective function and constraint penalty. An individual with a better value of objective function later has a higher fitness value. Each individual is represented by a chromosome in which the values of design variables are converted into a binary string of 0 and 1 characters. This conversion is called "encoding" of the individual. Each population of individuals (a set of design points) is altered via the genetic operations of "selection," "crossover," and "mutation." In this population individuals may be referred to as "parents" and from these "parents" come "children" through the genetic operations. These "children" in turn become the "parents" of future "children."

Each individual in a population is evaluated and its fitness value is determined. A new population of designs is selected from the original set of designs: a process based on a survival of the fittest scheme. New designs are created by the genetic crossover operation: chromosomes of two individuals are crossed at two points and the genes between those points are swapped in the two chromosomes resulting in

two new individuals. Genetic operation of mutation changes a value of a randomly selected gene in a chromosome to further increase the variability of the population and avoid stagnation in the evolution process [16].

2.4.1 Multi-Island Genetic Algorithm. The Multi-Island Genetic Algorithm is an exploratory technique that is capable of using real, integer, and discrete parameters. It is well-suited for discontinuous design spaces though not well-suited for long running simulations where each simulation takes several minutes or more. Parallel processing is available for implementation [16]. Its features are:

- Divides the population into several islands
- Performs traditional genetic operations on each island separately
- Migrates individuals between the islands
- Searches many designs and multiple locations of the design space

Multi-Island Genetic Algorithm allows the preservation of the best individuals from the previous generation without alteration. This operation is called *elitism*. Elitism guarantees that the best genetic material is carried over to the child generation.

The selection operation in Multi-Island Genetic Algorithm employs the so-called *tournament selection* scheme. In the tournament selection, the best individuals are selected not from the whole population, but rather from a smaller subset of randomly selected individuals. This scheme allows for duplicate individuals in the child population. The size of the subset from which each best individual is selected is calculated using the value of the relative tournament size. Reducing the relative tournament size increases the randomness in the selection process. Increasing the tournament size results in more duplicates of the best individuals in the child population.

The main feature of the Multi-Island Genetic Algorithm that distinguishes it from the traditional genetic algorithm is the fact that each population of individuals is divided into several sub-populations called *islands*. All traditional genetic operations

are performed separately on each sub-population. Some individuals are then selected from each island and migrated to different islands periodically. This operations is called *migration*. Two parameters control the migrations process:

- *Migration interval* - which is the number of generations between each migration
- *Migration rate* - which is the percentage of individuals migrated from each island at the time of migration [16]

2.4.2 Neighborhood Cultivation Genetic Algorithm. The Neighborhood Cultivation Genetic Algorithm (NCGA) is multi-objective exploratory technique that is capable of using real, integer, and discrete parameters. It is well-suited for discontinuous design spaces though not well-suited for long running simulations where each simulation takes several minutes or more. Parallel processing is available for implementation [16]. Its features are:

- Each objective is treated separately
- A pareto front is constructed by selecting feasible non-dominated designs

In the Neighborhood Cultivation Genetic Algorithm, each objective is treated separately. The crossover process is based on the *neighborhood cultivation* mechanism where the crossover is performed mostly between individuals whose values are close to one of the objectives. By the end of the optimization run, a pareto set is constructed where each design has the *best* combination of objective values and improving one objective is impossible without sacrificing one or more of other objectives [16].

2.4.3 Non-dominated Sorting Genetic Algorithm. The Non-dominated Sorting Genetic Algorithm (NSGA-II) is multi-objective exploratory technique that is capable of using real, integer, and discrete parameters. It is well-suited for discontinuous design spaces though not well-suited for long running simulations where each simulation takes several minutes or more. Parallel processing is available for implementation [16]. Its features are:

- Each objective is treated separately
- A pareto front is constructed by selecting feasible non-dominated designs

In the Non-dominated Sorting Genetic Algorithm (NSGA-II) the selection process is based on two main mechanisms, *non-dominated sorting* and *crowding distance sorting*. By the end of the optimization run a pareto front set is constructed where each design has the *best* combination of objective values and improving one objective is impossible without sacrificing one or more of other objectives [16].

2.5 A History of Antenna Optimization with Genetic Algorithms

In [48], the authors use a three-objective pareto genetic algorithm to optimize Log-Periodic Monopole Arrays (LPMA). Their design, though it does not place a stringent demand on the array for remaining Log-Periodic, does reward the design if it is LPMA. Compared in the research are three genetic algorithms. Simplex and Newton-based methods were initially used and led to satisfactory results, but results with these local-search algorithms produced local minima in very different areas of the search space, even between runs for the same algorithm. Upon using a multi-objective search algorithm, results were not only exceeded but remained consistent from run to run.

Villegas et al detail in their paper, [54], the design of low-cost antennas that adhere to strict requirements of size while retaining remarkable characteristics in bandwidth, gain, and mulitband operation. The specific application is for patch antennas in cellular phones. To achieve their results, they turn to electromagnetic genetic algorithm optimization (EGO). Their results are as good as 10 dB improvements for particular frequencies in the application specific bandwidth.

Rahmat-Samii advocates the use of Particle Swarm Optimization (PSO) in Engineering Electromagnetics [46]. In the paper, PSO is said to have the versatility and ability to optimize in complex multimodal search spaces for applications in non-differentiable cost functions. PSO is a robust stochastic evolutionary computation

technique whose basis comes from the social behavior of a swarm of bees, fish, and other animals. It mimics their ability to search a landscape for the most fertile feeding location.

The design of automobile antennas is augmented with different GAs in Kim's paper, [33]. Kim ultimately uses the Non-dominated Sorting Genetic Algorithm (NSGA) to optimize the automobile antennas because of its ability to find a set of pareto-optimal solutions instead of finding a single optimal solution. The multi-objective algorithms produces considerably better results for the specific applications of FM radio, Global Positioning System (GPS), and Satellite Digital Radio Service (SDARS).

The Air Force Research Laboratory's Space Vehicles and Sensors Directorates attained a low-cost improvement to an existing antenna platform using evolutionary genetic algorithms [10]. Their goal for improving the accuracy and reliability of the Digital Ionospheric Sounding System (DISS) network was met through the use of both NEC4 and a proprietary genetic algorithm. After implementing the improved design, errors associated with measuring the frequencies of interest in the ionosphere decreased from 16% error to 1.6% error. This improvement met their required specification of 5% or better error. Implementation of the new design also saved the Air Force thousands of dollars by manipulating an existing platform and increasing its performance rather than buying an entirely new antenna and having it installed.

2.6 Over-the-Horizon Radar Optimization With Genetic Algorithms

The "No Free Lunch" Theorem [56] maintains that costs are allowed for potential benefits. This theorem states that a GA incorporating problem domain knowledge is most effective. Thus a GA that actively searches for antenna designs while running those results through code which evaluates the design's viability is an effective problem solving algorithm [53]. Antenna optimization is applicable to all areas of *wireless* communication where the components' associated antenna is such a vital part. Some are easy to build for their given use, others prove difficult to design and maintain a

yield of most favorable results. To the end of optimization, we see several techniques in implementing GAs.

The Method of Moments (MOM) is considered an exact solution to electromagnetic problems. The full-wave MOM simulation can be used in conjunction with optimization applications. MOM is quite costly in computation time; its product, however, is superb [54], [24]. Parallel computing in this method allows for speed but requires super-computing (processor nodes). Though the requirement for a powerful computer is stringent, it is a worthwhile expense if the researcher can afford it, for the robust product and accuracy of the results are achieved in a much quicker fashion. The use of direct Z-matrix manipulation (DMM) proves to be integral to the GA/MOM integration [26]. Along with only needing to be filled once prior to the GA optimization process, the Z-matrix uses matrix portioning and pre-solving to reduce the time for optimization even further.

GAs can be applied on a variety of different antennas. They have been demonstrated useful on linear arrays and planar arrays as well as linear and planar array combinations [7]. Ares-Pena et. al. [7] validate the GA useful for escaping local minima and maxima solutions. They combine the power of GAs with Simulated Annealing (SA) to produce a hybrid GA capable of solving the problem of array thinning. This solution starts with an aperture distribution accomplished by procedures found in [11], but results in [19] indicate that SA is a poor approach for LPDA antennas.

Correia et al have very useful results for Yagi-Uda antennas in [14]. They find that optimization of gain and impedance is not always enough for applications and that the bandwidth must also be optimized. They do this through three techniques: the use of GAs, the use of conjugate-gradient, and the use of random search. Their studies find that GAs surpass the other two methods in every aspect except the convergence rate of the conjugate-gradient method. The iterative nature of GAs is particularly useful when variable and parameter numbers are large. Even then the GA will produce a marvellous result, optimized for the given constraints and even

suited for designing banded Yagi-Uda antennas. In [29], Jones et. al. produce a method for optimizing the element spacings in a Yagi-Uda antenna by using NEC2. They show that though slower than local optimizers, GAs' ability to solve problems with no clear starting point is invaluable and without rival.

2.7 Antenna Models

2.7.1 Dipole Antenna. Dipole antennas are very common. The theoretical work for the thin antennas has been confirmed primarily for length-to-diameter ratios greater than 15 [27]. The formula describing this antenna is very simple and is valid only when the half length of a center-driven antenna is not much longer than a quarter wavelength. The reduced form of this equation is

$$Z_i = R(kl) - j\left[120\left(\ln\frac{l}{a} - 1\right)\cot kl - X(kl)\right] \tag{2.1}$$

where Z_i = input impedance, Ω, of a center-driven cylindrical antenna of total length $2l$ and of radius a. $kl = 2\pi(l/a)$ = electrical length, corresponding to l and measured in radians. For calculating the functions $R(kl)$ and $X(kl)$, the following simple third-order polynomials approximate to within 0.5 Ω [27]

$$R(kl) = -0.4787 + 7.3246kl + 0.3963(kl)^2 + 15.6131(kl)^3 \tag{2.2}$$

$$X(kl) = -0.4456 + 17.0082kl - 8.6793(kl)^2 + 9.6031(kl)^3. \tag{2.3}$$

An example of the dipole can be seen in Figure 2.5. The current induced or excited on the antenna structure can be seen in Figures 2.6 and 2.7

An example of using two dipoles on the roof is also helpful in this study. This example is pictured in Figure 2.8. Their respective currents as well as phase and magnitude may be seen in Figures 2.9 and 2.10.

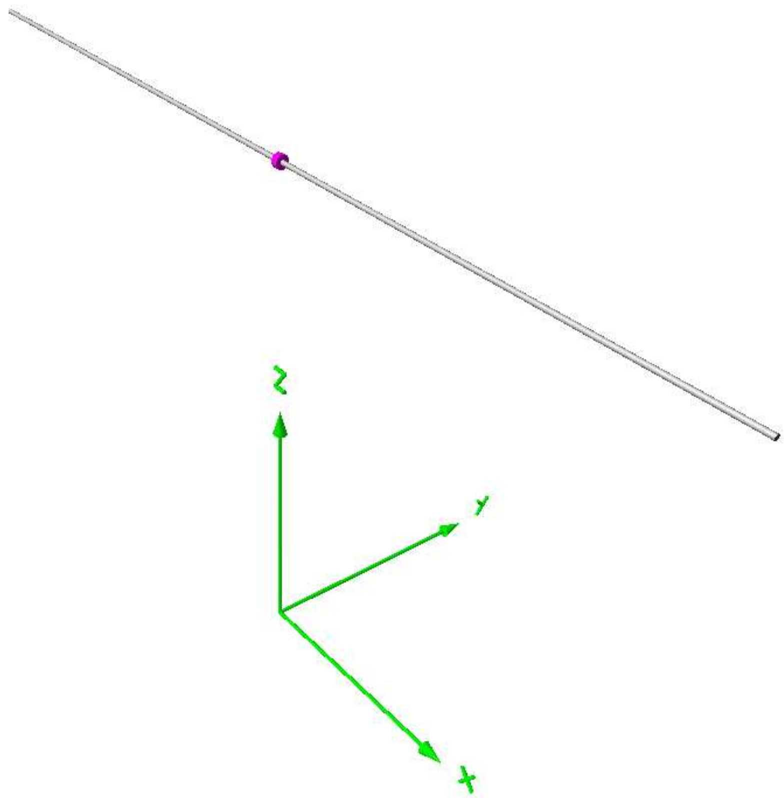


Figure 2.5: A typical dipole antenna

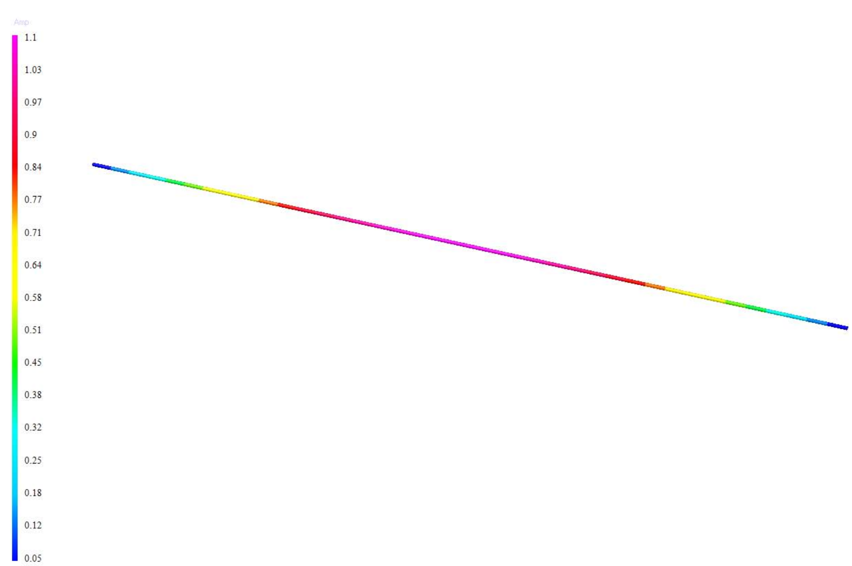


Figure 2.6: The current on a typical dipole antenna

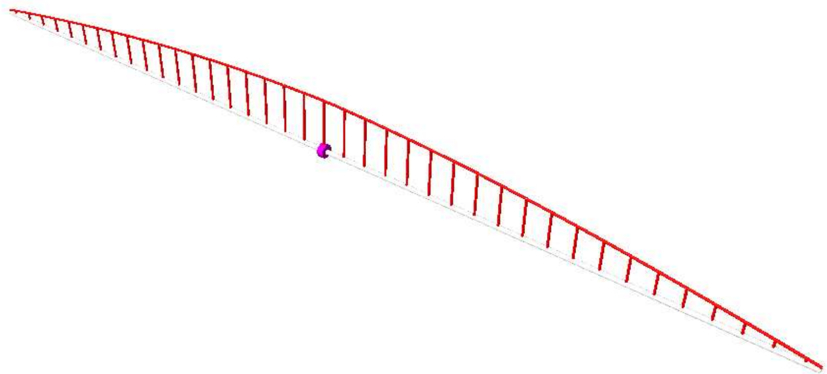


Figure 2.7: The phase and magnitude of the current on a typical dipole antenna

2.7.2 Rhombic Antenna. The rhombic antenna is constructed as an elevated diamond whose sides are from two to several wavelengths long. It is used in the transmission and reception of high-frequency waves propagating through the ionosphere. If it is terminated at its apex with a resistance equal to its characteristic impedance, it can act as a directional antenna.

When compared to the half-wave dipole antenna with equal power input, the relative advantage in power gain is given by Equation 2.4 found in [27]

$$G_{dB} = 20 \log \frac{E_r}{E_d} \tag{2.4}$$

where E_r is the field strength produced by the rhombic antenna and E_d is the field strength produced by the dipole antenna.

2.7.3 Panel Antenna. The panel antenna is made from simple radiating elements mounted over a reflecting screen. They typically use full-wavelength dipoles, half-wave dipoles, or slots at radiating elements. Common advantages for the Panel antenna over the Yagi-Uda antenna are [27]:

- More constant gain, radiation patterns, and VSWR over a wide bandwidth

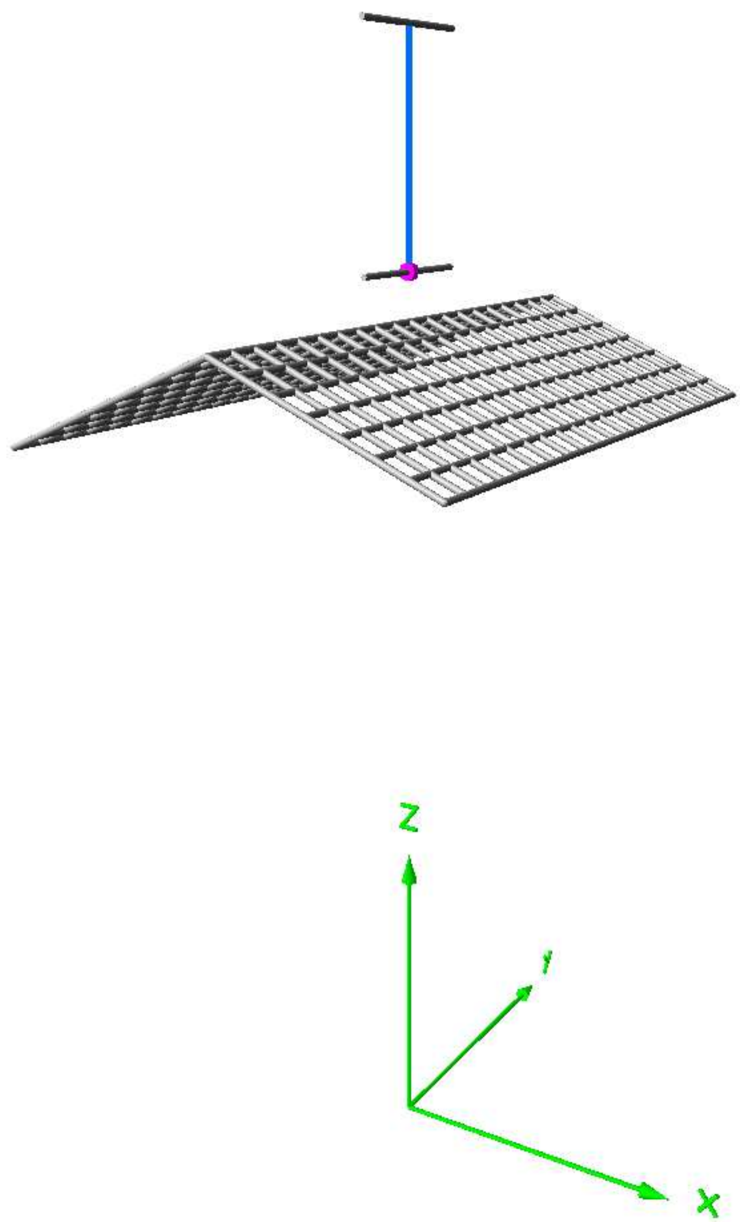


Figure 2.8: Example of two dipoles displayed on top of a roof

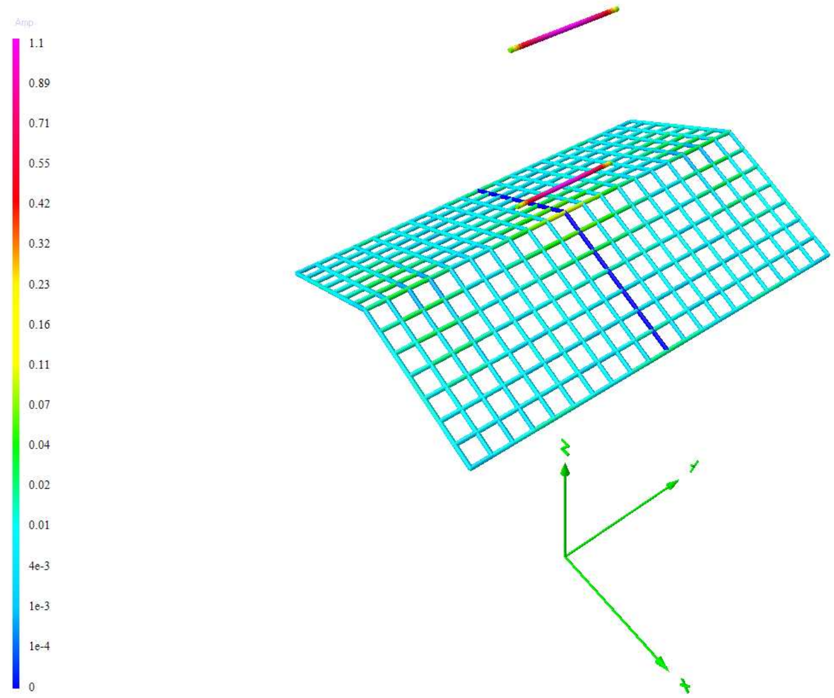


Figure 2.9: The currents associated with two dipoles on a roof

- A more compact structure. The phase center is therefore maintained closer to the axis of the supporting structure. This provides better control in the azimuth radiation pattern.
- Very low coupling to the mounting structure
- Low side and back lobes.

An example of a panel antenna is shown in Figure 2.14 and its antenna pattern is seen in Figure 2.15. The phase and magnitude for the antenna are shown in Figure 2.16 and the polar pattern is shown in Figure 2.17

2.7.4 Helical Antennas. A helical antenna consists of either a single or multiple conductors wound into a helical shape. An example of one is seen in Figure 2.18. The helical antenna can radiate in many modes but normal and axial modes are the most common. In the normal mode, radiation is received or transmitted from the broadside of the antenna. In the axial mode, the radiation is maximum along

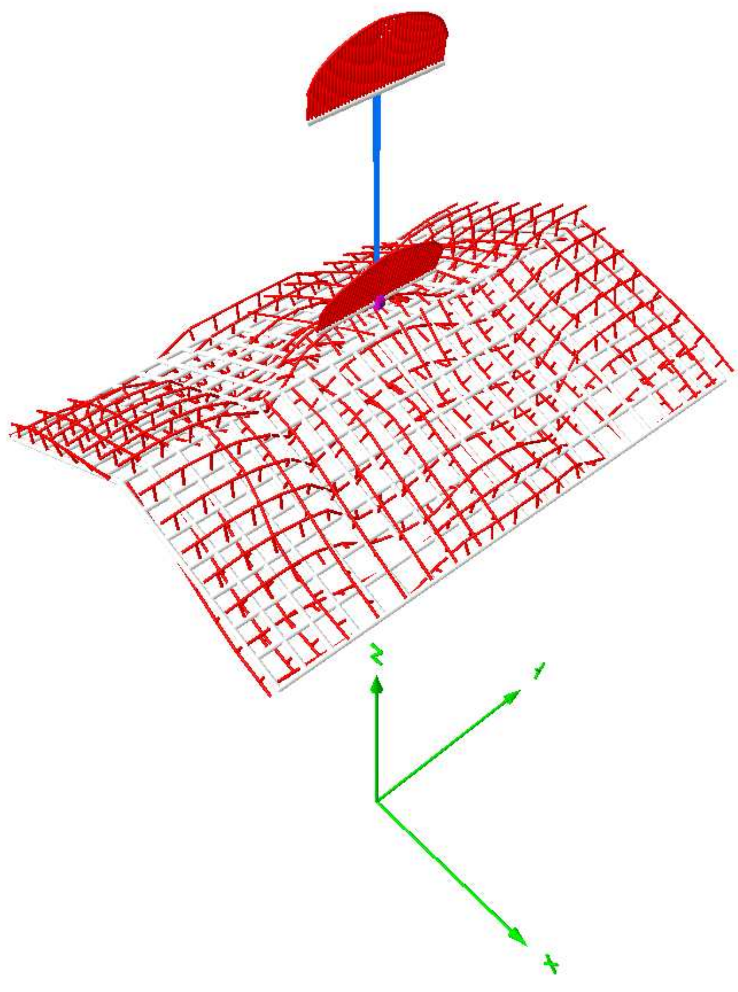


Figure 2.10: The phase and magnitude for two dipoles on a roof

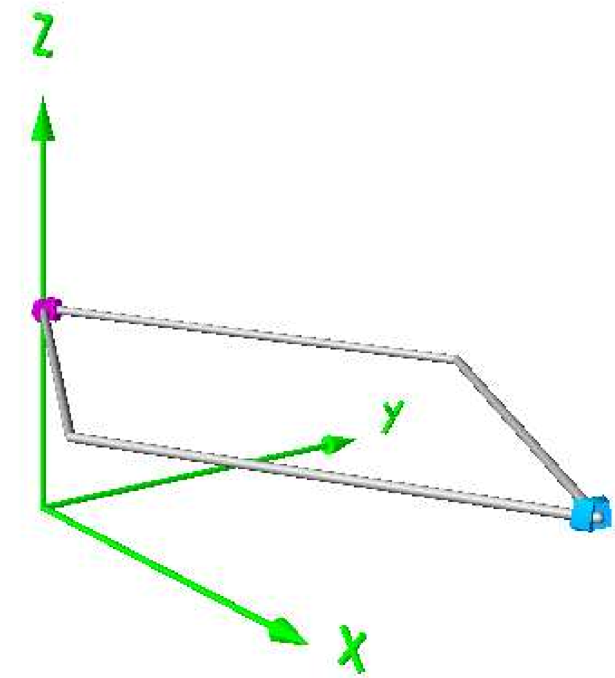


Figure 2.11: A typical rhombic antenna

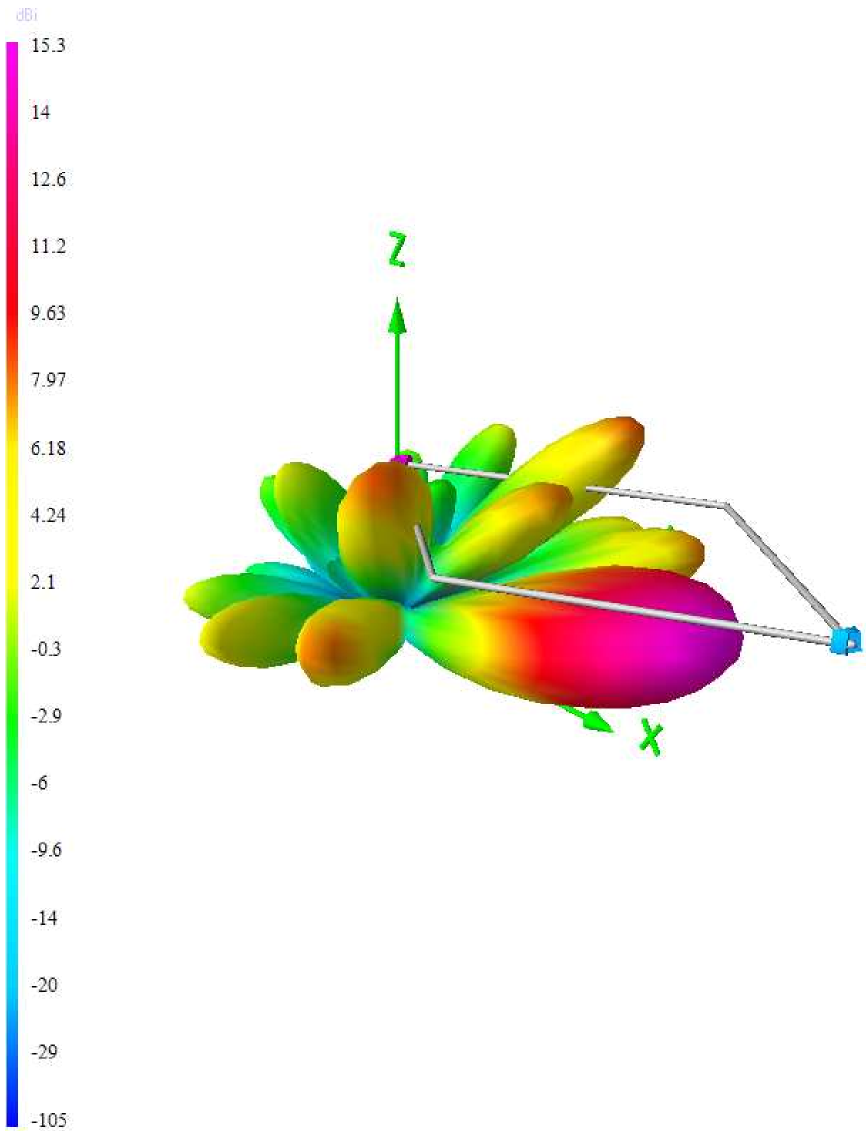


Figure 2.12: The antenna pattern for the typical rhombic antenna

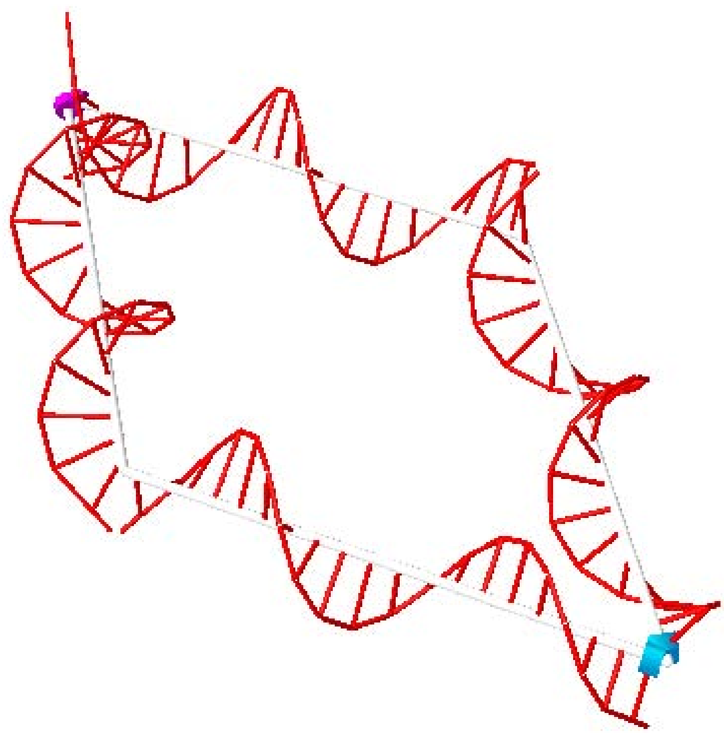


Figure 2.13: The phase and magnitude associated with the typical rhombic antenna

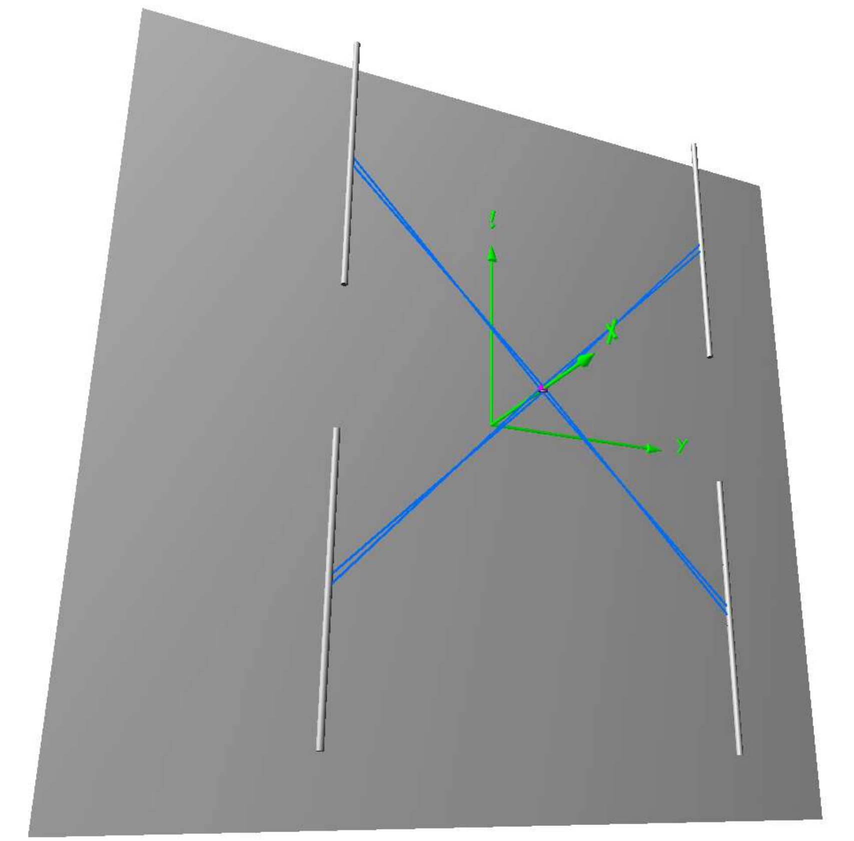


Figure 2.14: A typical panel antenna

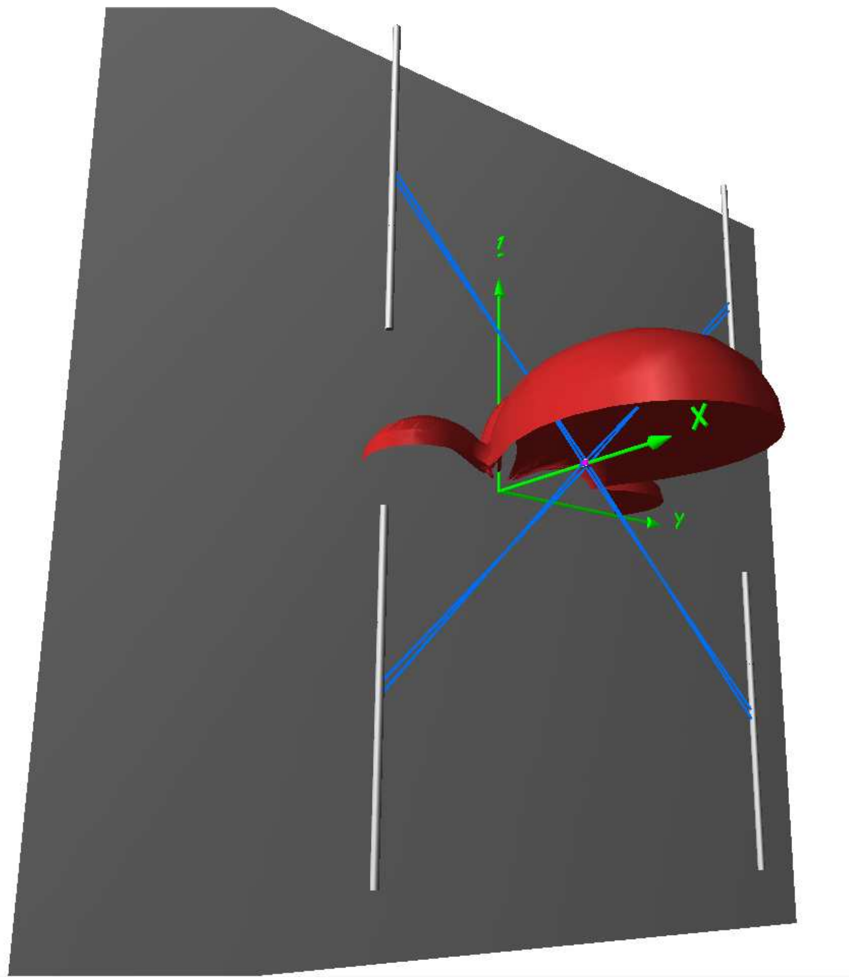


Figure 2.15: The antenn pattern for a typical panel antenna

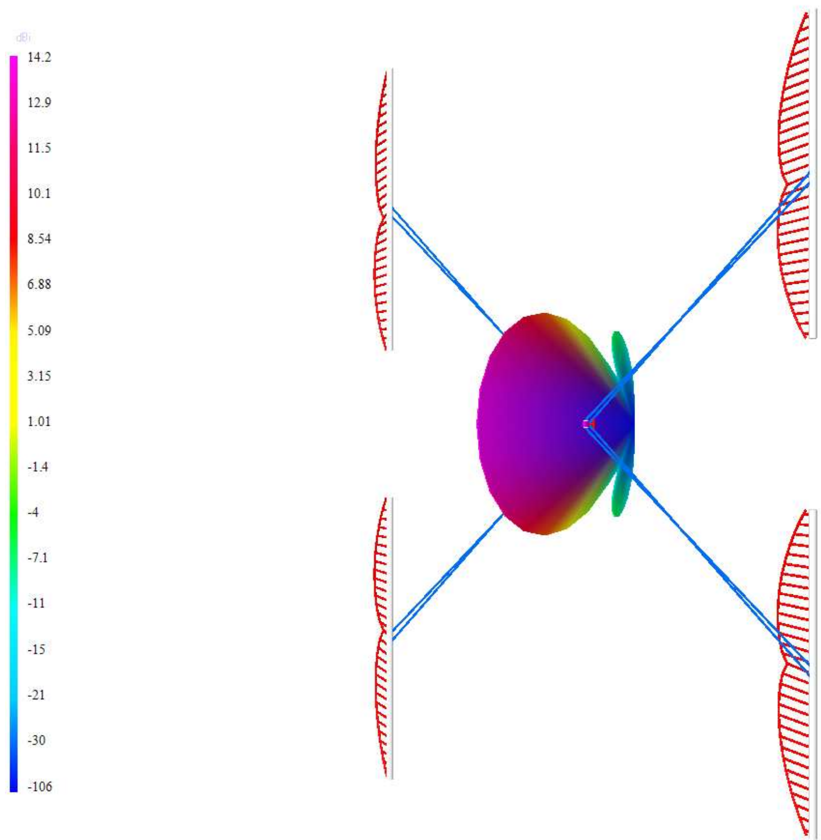


Figure 2.16: The phase and magnitude for a typical panel antenna

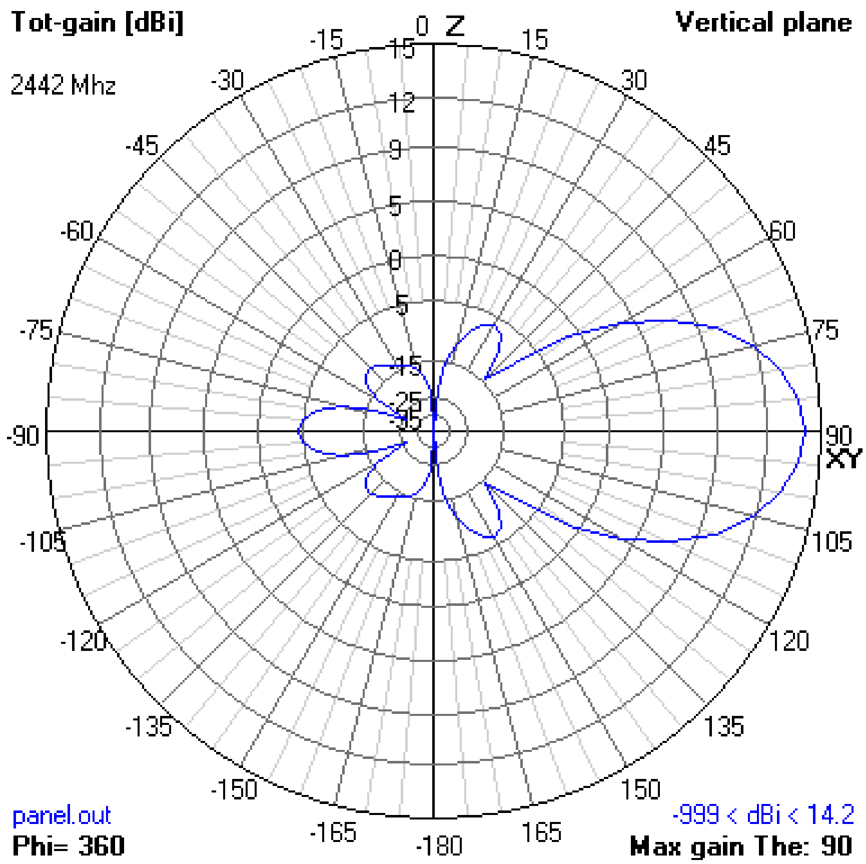


Figure 2.17: The polar pattern associated with the typical panel antenna

the helix axis if the helix circumference is of the order of one wavelength [27]. The basic concepts for this antenna were first described by Kraus in [34] and [35]. One advantage for the backfire helix antenna is that it does not usually require a ground plane.

The current for the antenna may be seen in Figure 2.19 and both the phase and magnitude for the example antenna may be seen in Figure 2.20

2.7.5 Yagi-Uda Antenna. The typical Yagi-Uda array is made of many parallel dipoles, with various lengths and spacings (see Figure 2.21). In the structure, only one of the elements is driven. The other elements act either as directors or reflectors. This was first described in 1926 by S. Uda [52] in Japanese and then by H. Yagi [57] in English. Generally, the longest element is the reflector, of the order $\lambda/2$, where λ is the wavelength associated with the frequency of interest. The director elements are always shorter in length than the driven element. One reflector is typical although many are allowed. It is usually spaced $\lambda/4$ from the driven element. Gain may be achieved by adding these numerous directors. The overall array pattern, $E(\theta)$, may be written as

$$E(\theta) = \sum_{i=1}^{n} I_i f_i(\theta) e^{(jkd_{i-1}\cos\theta)} \tag{2.5}$$

where n is the total number of dipoles in the array, $d_0 = 0$, and I_i is the maximum current amplitude of the ith dipole. $f_i(\theta)$ is defined as

$$f_i(\theta) = \frac{\cos(kh_i \sin\theta) - \cos kh_i}{\cos\theta} \tag{2.6}$$

where h_i is the half length of the ith dipole.

In this study, I_i is determined through the Method of Moments. The power gain, $G(\theta, \phi)$, may then be computed for the array by

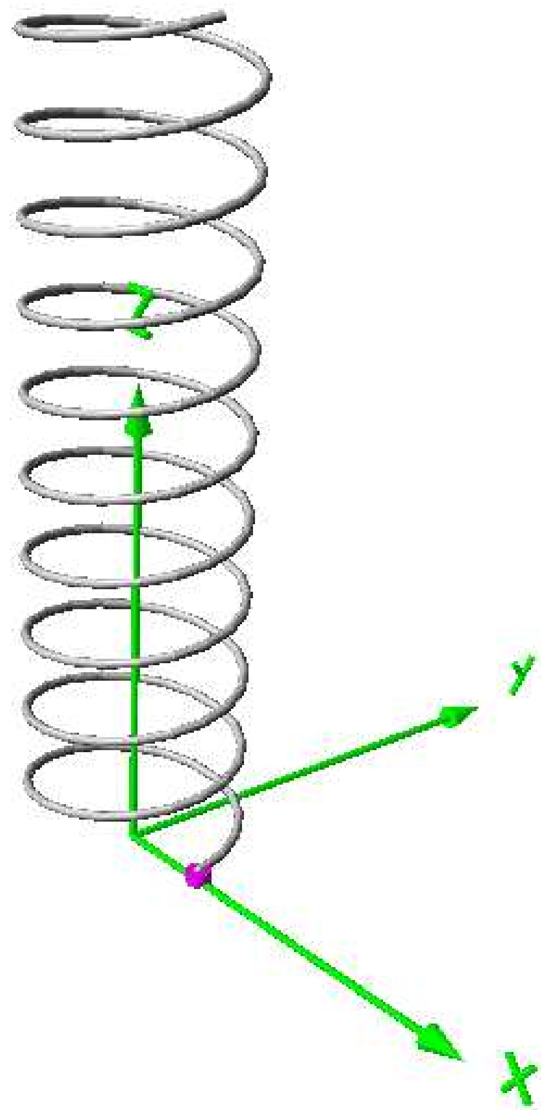


Figure 2.18: A typical helical antenna

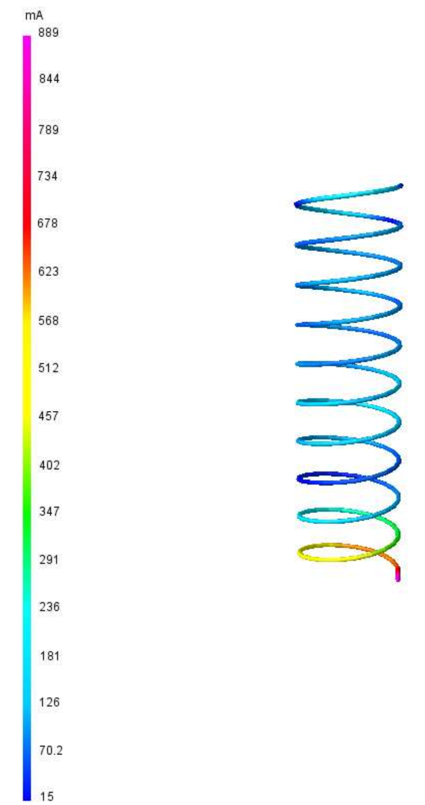


Figure 2.19: The current associated with a typical helical antenna

Figure 2.20: The phase and magnitude for a typical helical antenna

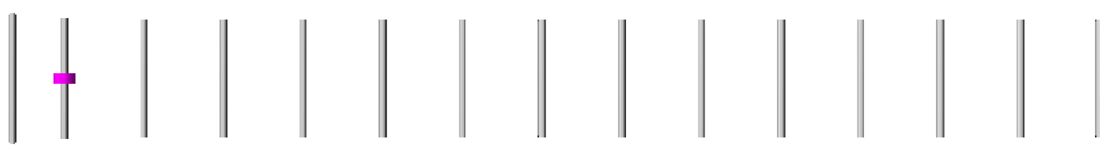


Figure 2.21: An example Yagi-Uda antenna

$$G(\theta, \phi) = 60 \left| E(\theta) \right|^2 / P_{in} \tag{2.7}$$

where

$$P_{in} = \nicefrac{1}{2} \left| I_{b2} \right|^2 R_{in} \tag{2.8}$$

represents the input power (P_{in}) and R_{in} is the input resistance while I_{b2} is the base current of the second driven element [27].

Though similar to the Yagi-Uda, the Log Periodic Dipole Array antenna differs in that its elements progressively differ in size along its main axis. The elements in the Yagi-Uda are typically uniform in size except for the reflecting element. Following is a detailing of the LPDA

2.7.6 Log Periodic Dipole Array Antenna. Since their introduction in the 1960s, LPDAs have been used for applications needing directional gain and a very

wide range of frequencies. Like the Yagi-Uda, the LPDA uses linear elements and may be pointed in the desired location for higher gain (see Figure 2.22). The application we focus on is passive RF sensing. For this application, it is helpful to have an antenna pattern with a focused beamwidth that is also wideband. The sources, television and radio towers, are non-cooperative and may be eliminated while reflections from targets can be detected well through proper antenna orientation.

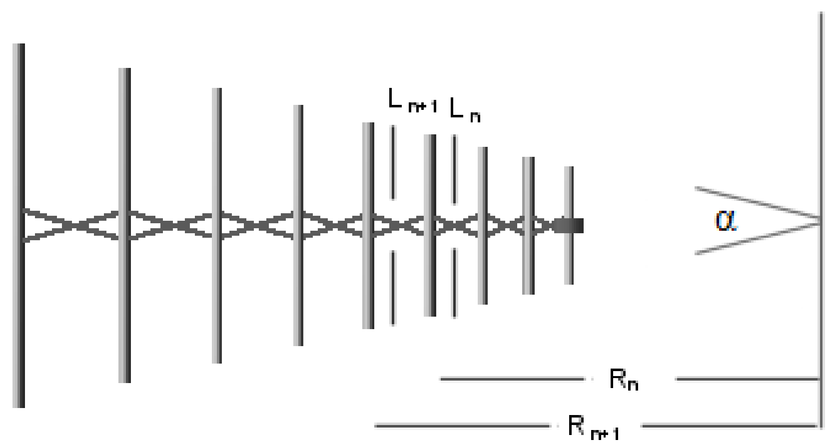


Figure 2.22: A typical LPDA antenna

τ is defined as

$$\tau = \frac{R_n}{R_{n+1}} = \frac{L_n}{L_{n+1}}, \tag{2.9}$$

where R_n, R_{n+1}, L_n, L_{n+1}, and α are defined in Figure 2.22. The parameters α and τ determine the gain, the impedance level, and the maximum VSWR of the antenna. It becomes important to choose τ and α wisely because of the chance for unwanted resonant effects. Constructive, and more importantly destructive, interference is a direct effect of spacing which is governed by τ [27].

Success has been seen by other authors who have used GAs to evolve antennas that outperform LPDAs [12, 30, 48, 49, 53, 55]. The freedom that the genetic algorithm is given in the design space allows it to change the length of the element, the

spacing between elements, and the diameter of the element; the antenna ceases to be a traditional LPDA [19]. However, the freedom in the design space must be given insightfully. For example, to allow wire lengths varying from 0 m to 1000 m for the frequency of 3 GHz would largely be a wasted search since at 3 GHz the wavelength is 10 cm. Similarly using a wire with only 10 cm of variance from 0 m for 3 MHz is not wise and does not allow for proper excitation on the wire of interest due to the large wavelength associated with the frequency.

2.8 The Method of Moments and Voltage Standing Wave Ratio inside GNEC

Initially considered was a MOM code developed at the Air Force Institute of Technology (AFIT). After evaluating the versatility of GNEC versus the *in-house* MOM code, the conclusion that using GNEC would ease post-simulation processing as well as interface very nicely with our genetic algorithm program, iSIGHT, was clear.

2.8.1 The Method of Moments.

The following is a summary of how the method of moments can be used to solve for the current on a wire. This summary is taken from [51] and [19].

Given a wire whose dimension stretches in the z-axis, the current is defined as $I(z')$ and may be calculated as follows. First, the electric field $E^i(z)$ on the wire is defined as

$$-\int I\left(z'\right) K(z,z')dz' = E^i(z). \tag{2.10}$$

The kernel function, $K(z, z')$, can vary depending on formulation of the integral equation. Here $K(z, z')$ is closely related to an underlying Green's function.

Several assumptions about the wire must be made:

- The wire is sufficiently narrow that it can be treated as a one-dimensional strand.

- All current flows in a strand at the center of the wire.
- A one-dimensional evaluation is not only sufficient but accurate.

Pocklington's equation [51] is one form of Equation 2.10 for a dipole

$$\frac{\text{- 1}}{\mathrm{j}\omega\varepsilon_{\mathrm{o}}}\int_{\frac{-L}{2}}^{\frac{L}{2}} I(z')\left(\frac{d^2\psi(z,z')}{dz^2}+\beta^2\psi(z,z')\right)dz' = E_z^i(z) \tag{2.11}$$

where $\psi(z,z')$ is the free-space Green's function $\frac{e^{-j\beta R}}{4\pi R}$, R is the distance between the point of observation and the origin, β is the wavenumber, and L is the length of the wire. Equation 2.11 has an integrable point of singularity at $z = z'$.

With a series of weighting functions named F_n, we can approximate $I(z')$ by using one weighting function per wire segment.

$$I(z') = \sum_{n=1}^{N} I_n F_n(z') \tag{2.12}$$

where F_n could be many things to include a square wave, a series of pulses, or a simple sinusoidal wave.

Using Equation 2.12, Equation 2.11 becomes

$$-\int_{-\frac{L}{2}}^{\frac{L}{2}} \sum_{n=1}^{N} I_n F_n(z') K(z_m, z') dz' \approx E_z^i(z_m) \tag{2.13}$$

If $F_n(z') = 1$ for z' in $\Delta z_n^{'}$ and 0 otherwise, then Equation 2.13 can be transformed into

$$-\sum_{n=1}^{N} I_n \int_{\Delta z_n'} K(z_m, z') dz' \approx E_z^i(z_m) \tag{2.14}$$

simply by taking the integral outside of the equation.

Here we can say that

$$f(z_m, z_n^{'}) = -\int_{\Delta z_n} K(z_m, z')dz'. \tag{2.15}$$

From this, Equation 2.14 becomes

$$I_1 f(z_m, z_1^{'}) + I_2 f(z_m, z_2^{'}) + \cdots + I_N f(z_m, z_N^{'}) \approx E_z^i(z_m). \tag{2.16}$$

with the wire divided into N segments, each having the length of $\Delta z_n^{'}$. The current, which we are solving for is the unknown constant I_n.

Equation 2.16 is now in a useful form once the structure is broken into segments. The accuracy of the equation grows as the amount of segmentation increases. This segmentation may be defined in the NEC4 code which is part of the methodology in experimental design.

2.8.2 Voltage Standing Wave Ratio (VSWR). The VSWR quantifies the interference from reflected waves. This is directly related to impedance mismatching and is lowest when the highest voltage and the lowest voltage induced or excited on the antenna are close in value.

The reflection coefficient, Γ, is calculated by

$$\Gamma = \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \tag{2.17}$$

where Z_{in} is the transmission line impedance and Z_o is the complex antenna impedance for specific frequencies. The VSWR may then be calculated, using Equation 2.17, as follows:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}. \tag{2.18}$$

The Front to Back Ratio (FBR) is also an important parameter for directional antennas though not considered in this study. Knowing that to increase gain often means to increase size, another focus of this study is to increase the main lobe power gain while retaining the antenna's original size and a low VSWR value [9]. The theory behind GNEC and its executables is next summarized and explained.

The purpose of the LPDA experimental design is to both minimize antenna structure size and maximize the power gain for that antenna, all while reducing the VSWR.

2.9 Justification

By using the MOM code, precision is ensured to the degree that the structure is segmented. This precision comes from the correlation of each segment to the far-field. By using MOM in analyzing each possible antenna design, accurate assessments can be made about the validity and improvement of each design without having to implement each design and test it in a real-world setting.

OTHR may be developed under several configurations. These include array configurations and dish arrangements. The most widely used of these are antenna arrays. Excellent progress has been made on this approach in Australia. In [31], Junker et al explain the optimization of antenna arrays with variable interelement spacing. However, they do not consider the mutual coupling that is crucial to the understanding of large arrays such as OTH arrays. Work in the area of mutual coupling has been accomplished in [37] by Lee and provides an excellent basis for application to OTHR.

Contrary to past performances by OTH radars and their adaptations to differing tasks such as quick changes in directional searches, antenna optimization provides a reasoned solution that is possible to implement. The efficiency that its implemen-

tation provides must first be evaluated through simulation and then in a real-world application.

PRS radar may be implemented in either a directional or an omni-directional manner. In either case, the ability to focus on reflected transmission and not the direct transmission of the signal from its source is crucial. This may be approached with several different antenna structures, the most popular being Yagi-Uda, dipole, disk cone, and LPDA structures (see Appendix A). The consideration of mutual coupling in the design of either one of these structures remains crucial to the successful designing and implementation of PRS platforms. This also begins through simulation and with the chosen *best* antenna from the simulations comes validation. Validation may be done through real-world implementation of that antenna. Comparison of the simulated antenna with the implemented antenna provides the validation of the process.

III. Methodology for Designing, Testing, and Analyzing Antennas

This chapter focuses on both the high and low levels of designing antennas with the use of GAs. Yagi-Udas and LPDAs were used as the starting point in antenna design and optimization and the justification for this is detailed. The experiment's techniques for iterating on as well as processing the computational results from each antenna are also characterized.

Whereas the typical approach in designing antennas is to lean heavily on theory and understanding of the operational characteristics of a given antenna, the method presented here is largely based on computational iteration. The genetic algorithm used alters an initial antenna, evaluates its performance, compares it to the results of previous designs, and progresses by building upon improvements.

3.1 High Level Design of Antennas

Approaching automated antenna design and production with GAs requires the definition of both an initial antenna as well as the freedom that the modeling software is given in order to change and eventually improve upon that initial design. The defining of an initial antenna is the defining of a starting point. That starting point is the designer's decision about what a viable solution might look like. The degrees of freedom given in the variables defining the antenna and thus the antenna characteristics are the degrees of uncertainty in original design. They also define the search landscape that is to be covered by the GA. The accuracy of this definition and the extent of its search are the only limiting factors in finding the *best* antenna possible.

Finding the *best* antenna is an infinite search. It is a search that perhaps never ends because of the infinite amount of variations on a single starting point. But the convergence upon a *better* antenna can certainly be realized as well as proved to be an improved version of the original antenna. These *better* antennas hold great value in applications where signal processing constraints may be relieved simply through the gathering of better data.

Following are examples of the antennas chosen as starting points for the two applications of PRS and OTHR. Once chosen, these examples are used in the genetic algorithm as a basis to build upon and vary, synthesizing new antennas that are evaluated and compared to the previous designs.

3.1.1 Yagi-Uda. Yagi-Uda antennas, as discussed in Chapter II, are useful for directivity at particular frequencies. They are made of several elements. The rear element is a reflective element and right next to it is the driven element. The remaining elements are directive in nature and whose number can be as small as one or as many as is feasible. An example of this is shown in Figure 3.1 and the directivity related to the antenna pattern is seen in Figures 3.2 and 3.3.

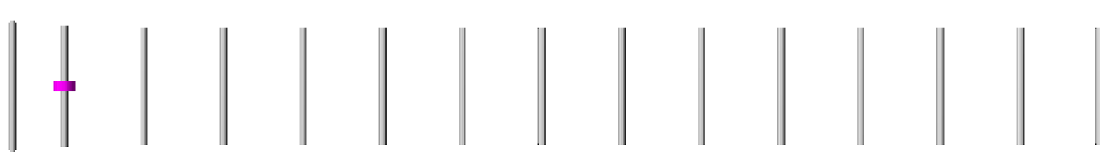


Figure 3.1: The Yagi-Uda example

This antenna, upon inspection of its characteristics and performance, is deemed viable and chosen as the starting antenna for the application of PRS radar.

3.1.2 LPDA. Log Periodic Dipole Arrays, as discussed in Chapter II, are particularly useful for a broad range of frequencies while still maintaining directivity.

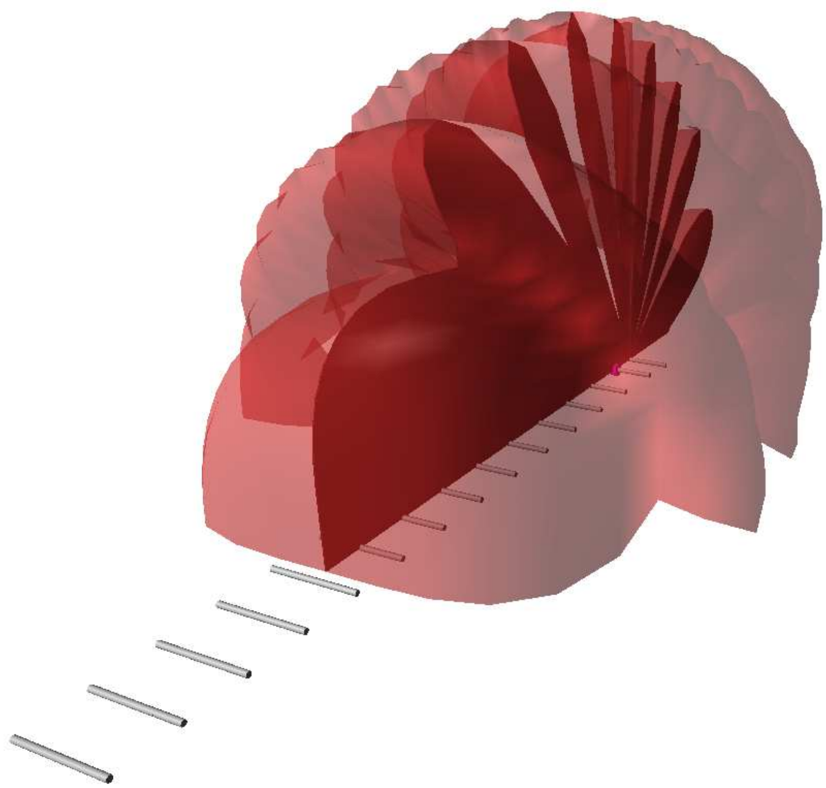


Figure 3.2: The antenna pattern for the Yagi-Uda example

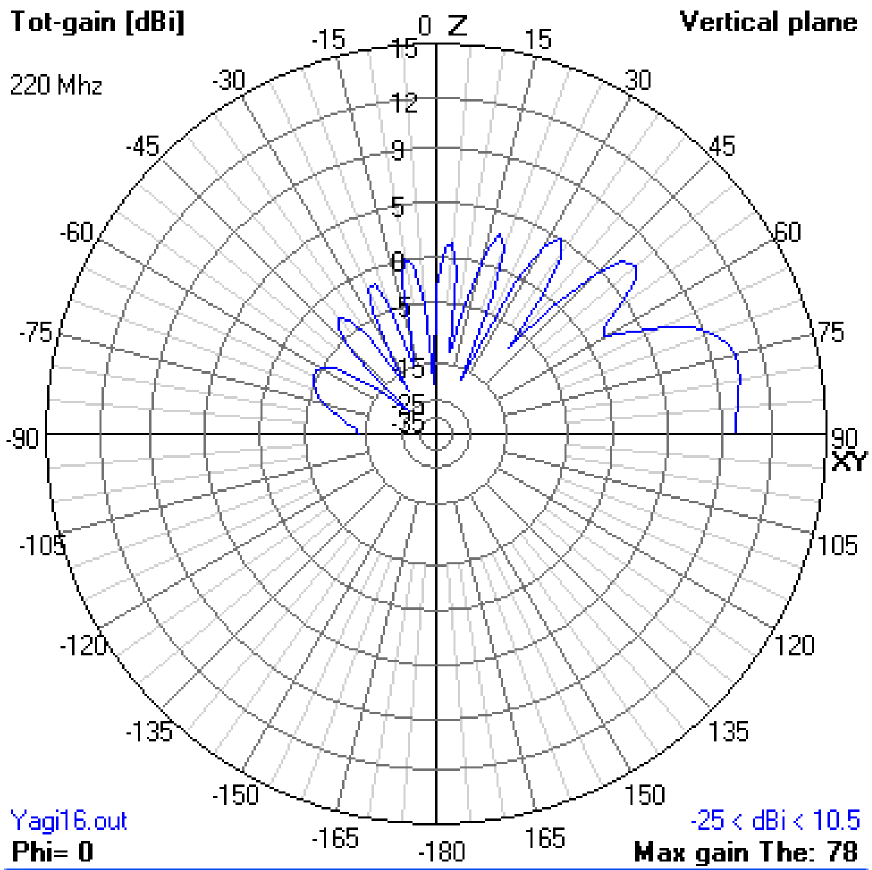


Figure 3.3: The polar pattern for the Yagi-Uda example

The example structure, depicted in Figure 3.4, has pattern characteristics that are directional as seen in Figures 3.5 and 3.6

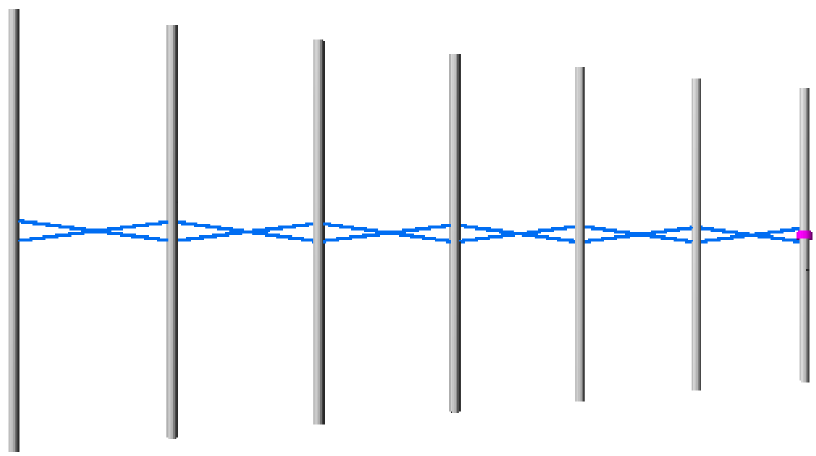


Figure 3.4: The LPDA example

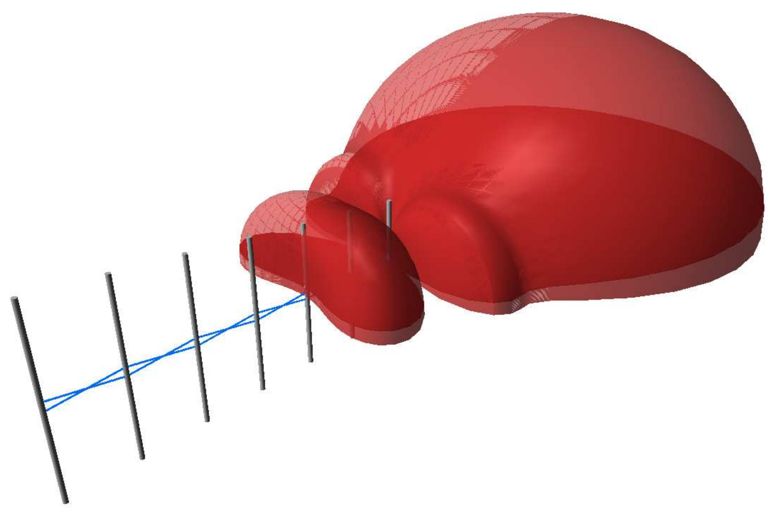


Figure 3.5: The antenna pattern for the LPDA example

Upon inspection of its characteristics and performance, this antenna is deemed viable and chosen as the starting antenna for the application of OTHR.

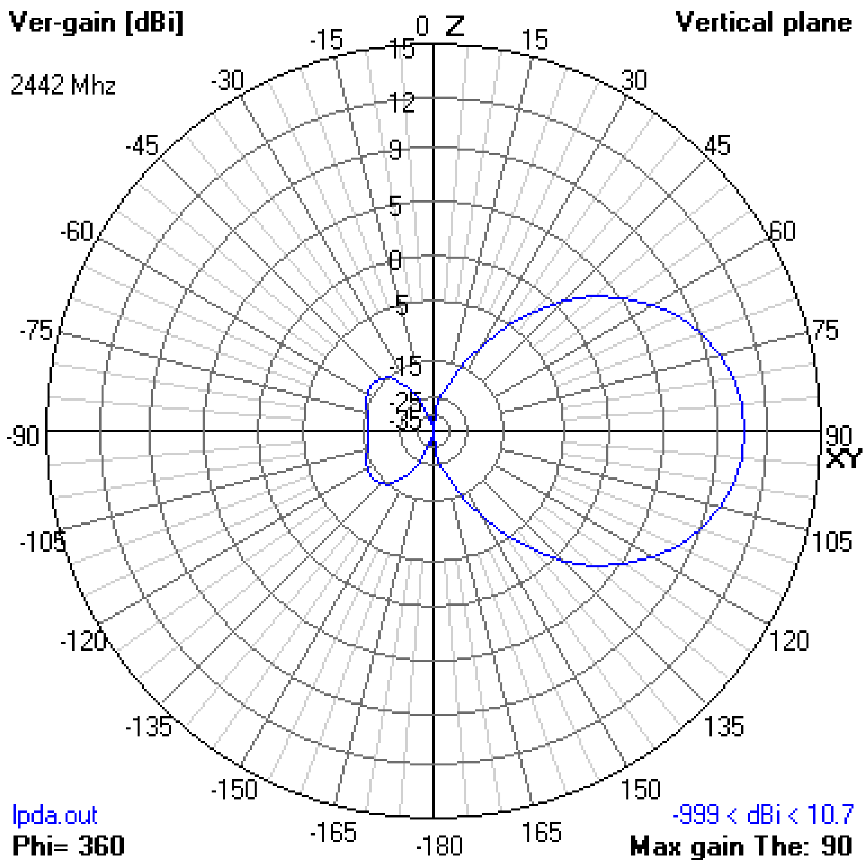


Figure 3.6: The polar pattern for the LPDA example

3.2 High Level Design and Implementation of Genetic Algorithms in iSIGHT

The three GAs considered, listed in Chapter II Section 2.4, are each suitable for antenna optimization and each with their own techniques as just listed, but the Non-dominated Sorting Genetic Algorithm (NSGA-II) is used in this study. The NSGA-II has the multi-objective ability that the Multi-Island Genetic Algorithm lacks. It develops an equally weighted aggregated fitness function by selecting feasible and non-dominated designs. This produces a well rounded antenna and maximizes each objective as best it can without diminishing the performance of other objectives. These characteristics are similar to the Neighborhood Cultivation Genetic Algorithm but only the NSGA-II is used in this study.

3.3 High Level Design and Integration of GNEC Inside of iSIGHT

When committing a program to be the *slave* of another *master* program, it is important to have a realizable framework formed inside the slave program. This framework may then be accessed and changed by the master program according to specifications laid down by the programmer. In doing this, the creator has fashioned together a tool that will produce, analyze, and rate thousands upon thousands of designs that would be unreasonable for a human to sort through. This process is very useful when using GAs to synthesize new antenna designs

3.3.1 High Level Design and Integration of GNEC. The slave program used in this thesis, as stated in Chapter I, is NEC4. The graphical interface used to illustrate results from NEC4 is GNEC. In creating a structure and the excitation on that structure, there are a myriad of commands but a few are of resounding importance in getting started and are illustrated in Figure 3.7, taken from [40].

These commands, among others, may be used to setup a framework that the master program uses to create a new antenna with each iteration. Because thousands of antennas are being created, it is important to minimize the run time of each an-

“create wire” “tag” number # of segments X,Y,Z start point (m) X,Y,Z end point (m) Wire radius (m)

```
CE
GW 1,  6,  0.0000,  0.0000,  0.0000, -0.0166,  0.0045,  0.0714,0.001
GW 2,  5, -0.0166,  0.0045,  0.0714, -0.0318, -0.0166,  0.0170,0.001
GW 3,  5, -0.0318, -0.0166,  0.0170, -0.0318, -0.0287,  0.0775,0.001
GW 4,  8, -0.0318, -0.0287,  0.0775, -0.0318,  0.0439,  0.0140,0.001
GW 5,  5, -0.0318,  0.0439,  0.0140, -0.0318,  0.0045,  0.0624,0.001
GW 6,  4, -0.0318,  0.0045,  0.0624, -0.0106,  0.0378,  0.0866,0.001
GW 7,  6, -0.0106,  0.0378,  0.0866, -0.0106,  0.0257,  0.0230,0.001
GE 1
EX 0,1,1,0,1,0,0,0
FR 0,1,0,0,1600.0000,0.0
EK 0
GN 1,0
RP 0,33,36,1011,-81.0,0.0,5.0,5.0
EN
```

GE 1 — End of Geometry information—the 1 indicates the presence of a ground plane

EX 0,1,1,0,1,0,0,0 — Means of excitation

1600.0000 — Frequency (MHz)

EK 0 — type of thin wire approximation (the simplest is specified here)

GN 1,0 — Ground Plane (perfect, infinite)

-81.0,0.0,5.0,5.0 — θ_o,ϕ_o,θ step, ϕstep

RP — Radiation Pattern

Figure 3.7: Illustration of commands used in NEC4 and their descriptions [40]

tenna's simulation. One lengthy part in simulation is evaluating the total power gain and phase characteristics at several ϕ and θ points. When the goal is only to evaluate the total power gain at particular points, the NEC command may be configured so that only those points are calculated and the other information, being inconsequential to the GA, is bypassed. This will decrease total simulation time drastically.

To calculate 360 points in a single simulation in NEC4 takes approximately 3 seconds. If only 3 of those points are of interest, the total run time can be cut down to as little as 0.15 seconds. When running an optimization plan that will cover 100,000 antenna designs, this saves more than 79 hours! This is evidence that great amounts of effort and time can be saved by using a critical and thought-out approach in optimization planning and implementation.

3.3.2 High Level Integration of iSIGHT. The master program used in this thesis, as stated in Chapter I, is iSIGHT. The three GAs detailed in Section 3.2 are all included in iSIGHT 9.0. As a master program, iSIGHT is intuitive in setting up optimization plans. After tagging input variables and the outputs in the output file, the user has many options that get as detailed as desired. For example, a window can be set on each parameter that defines the minimum and maximum values allowed. An objective may be defined for both inputs and outputs. Weights may be set for objectives. Output values may be restricted to minimum or maximum values and, if violated, marked as either infeasible or not preferable in the output database created for each task.

In iSIGHT it is also possible to either define the method of optimization or to execute the default *optimization plan*. The default plan is a combination of techniques that the user has no control over, but the user can implement a customized technique whose details are all user controlled.

Run time can also be considerably truncated by allowing iSIGHT to run without turning on the solution monitor. The solution monitor severely slows down the computation time as graphs and data are streamed live to the window. Viewing this

window is reasonable at the beginning of runs when the validity of the task is still being evaluated but once a task is final, the solution monitor is better left off. The monitor will increase computation time by as much as 1000%. In addition to this, any information gathered in post-analysis of the solution monitor may easily be created using the text file output in "Task1.db." Task1.db is the database that holds all numerical values for the variables as well as the resulting outputs and ranks for each iteration. Graphs may be constructed from the database file as well as antenna designs pertaining to a specific number in the run counter.

When implementing NEC4 inside of iSIGHT, it is important to have the simcode setup so that it points correctly to NEC4's executable. It is easiest to do this in iSIGHT from the DOS command line. Executables associated with programs like MATLAB® are easier to implement without having to go to the DOS command line. NEC4 however is best used as though it were a script while a slave to iSIGHT. Further detailing of this and a thorough example is found in Appendix A.

3.4 Low Level Design of Antennas with iSIGHT

The examples for both the Yagi-Uda and the LPDA given earlier in this chapter are used as the basis for starting antennas in this thesis. These two antennas are improved upon and the Yagi-Uda is compared to previous work.

3.4.1 Yagi-Uda. To validate the procedure created by the integration of NEC4 into iSIGHT, the work found in [41] is reproduced and then the results of this research are compared to the research found in their document. Lohn et al's winning antenna from [41] is used as the starting point for Yagi-Uda antenna synthesis in this research. This antenna may be seen in Figure 3.8.

After placing this antenna into NEC4 and creating a template that iSIGHT may iterate upon, the constraints were placed on the Yagi-Uda antenna such that:

- 14 elements comprise the antenna

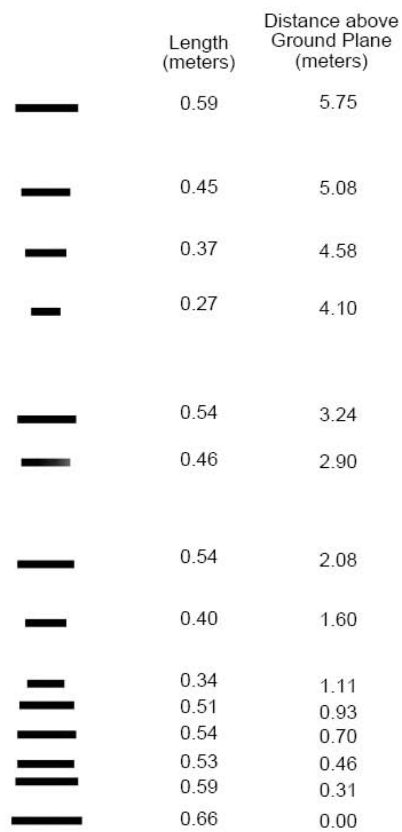


Figure 3.8: The winning antenna found in Lohn et al [41]

- The parameter y, the length of the antenna, is allowed to vary from 0 to 6 meters.
- The parameter x, which is half the length of each element, is allowed to vary from 0 to 0.5 meters.
- Less than 14 elements are allowed if the length of a given element is equal to zero
- The wire diameter varies from 1 mm to 2.5 mm.
- All elements within a given design are assigned the same radius value
- Gain at each frequency is calculated from $\phi = 0°$ to $180°$ at $45°$ increments.
- Elements are spaced no closer than 0.05λ, where λ is defined as 1.195 meters (associated with 235 MHz). This middle frequency choice resembles the methods used in [41].
- Gain at $\phi = 0°$ is maximized
- Gain at both $\phi = 135°$ and $180°$ is minimized.
- VSWR is minimized at the three frequencies of interest.

This antenna is then optimized for three frequencies: 219 MHz, 235 MHz, and 251 MHz.

3.4.2 LPDA. With the success of the Yagi-Uda antenna implementation, the LPDA is designed and iterated upon inside iSIGHT. The antenna seen in Figure 3.9 is used as a starting point. This antenna is allowed freedom in design parameters as follows:

- 12 elements comprise the antenna
- The parameter x, the length of the antenna, is allowed to vary from 0 to 85 meters.
- The parameter y, which is half the length of each element, is allowed to vary from 0 to 12 meters.

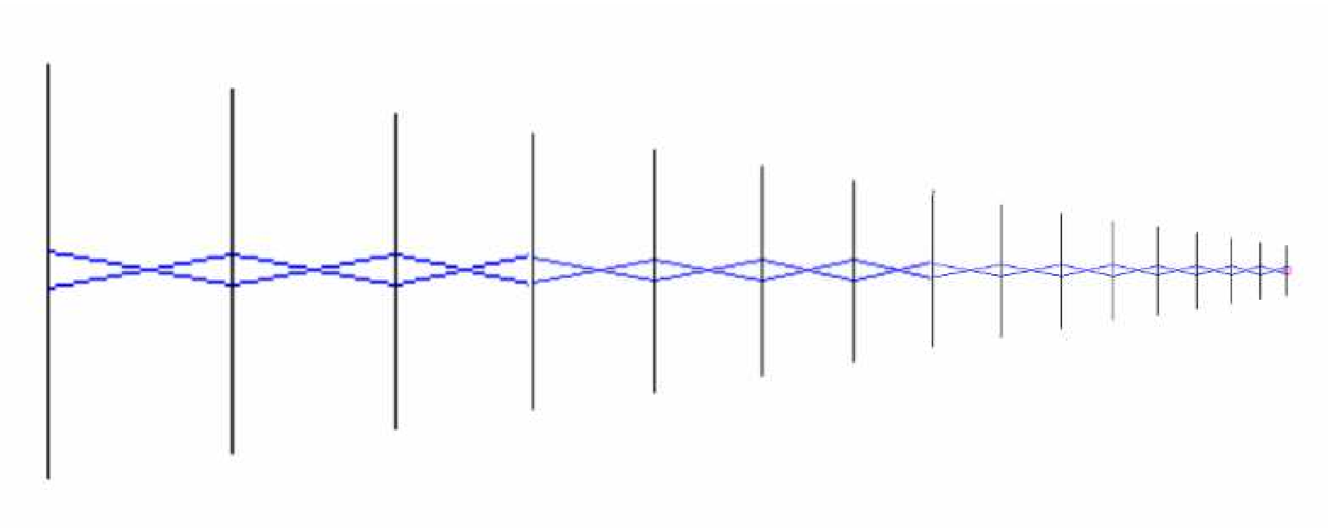


Figure 3.9: The LPDA antenna used as a starting point for antenna synthesis

- Less than 12 elements are allowed if the length of a given element is equal to zero
- The wire diameter varies from 1 cm to 4 cm.
- Gain at each frequency is calculated from $\phi = 0°$ to $180°$ at $45°$ increments.
- Elements were spaced no closer than 0.0015λ, where λ is 99.957 meters (associated with 3 MHz)
- Gain at $\phi = 0°$ is maximized
- Gain at both $\phi = 135°$ and $135°$ is minimized.
- VSWR is minimized at the three frequencies of interest.
- The length of the antenna is minimized.

3.5 Low Level Design and Implementation of Genetic Algorithm

Required for using the Non-dominated Sorting Genetic Algorithm (NSGA-II) is the definition of key parameters:

- Population Size

- Number of Generations
- Crossover Probability
- Crossover Distribution Index
- Mutation Distribution Index

Defining these parameters is the integral part in both finding an improved antenna and minimizing the time to search for that antenna. In finding the *best* antenna, a certain amount of iterations have to be performed, comparison of the bad antennas with the good and how much they vary shows a good indication of convergence to an appropriate solution. If this search continues too long after convergence has been achieved then wasted search time has been committed to an already "solved" task. The following information in Table 3.1, taken from [40], is useful in designing a genetic algorithm and specifying its parameters.

For items of interest in this thesis, the number of generations is 100 for the Yagi-Uda and 200 for the LPDA. The maximum population size in iSIGHT for the Non-dominated Sorting Genetic Algorithm (NSGA-II) is 500 for both the Yagi-Uda and the LPDA. For both antennas, the crossover probability is 0.90, the crossover distribution index is 20.0, and the mutation distribution index is 100.0. These values are also depicted in Table 3.2, where ν is the number of genes which refer to the number of random variables.

The number of genes, ν, for the two antenna cases is 29 random variables for the Yagi-Uda antenna and 25 random variables for the Log Periodic Dipole. In relation to the mutation distribution index, 100% of the chromosomes are subjected to mutation where one out of every ν is mutated. The crossover distribution index of 20.0 indicates that 20% of the chromosome may be switched with 20% of another chromosome; the probability of that happening being 90%.

These parameters construct a search that is fitting for both the Yagi-Uda and LPDA. In each run, 50,500 iterations were evaluated for the LPDA and 100,500 iter-

Table 3.1: Common genetic algorithm problems and possible solutions [40]

If…	Try…
It converges before getting to a good solution	Increasing exploration: increase the population, steady-state GA—increase percentage overlap (simple GA—lower crossover percentage), increase mutation.
It takes too long to converge	Decreasing exploration: do the opposite of above.
It goes to very different answers each time	Using speciation and niching to increase exploration of different hills. (discussed in next section)
The answer is somewhat poorer than you anticipated, especially from previous related GA runs	Looking for bugs! Check that you have changed over all constants and parameters if optimizing a new problem with a previously-functioning GA.
The following rows further breakdown the one above…	
If the fossil record shows abnormal improvement curves—e.g., improvement is constant and slow, even at first	Looking for bugs in the mating and mutation procedure. Insure the constants used are reasonable. Try using different population sizes, overlaps, and even crossover/mutation operators.
If the best individual shows some good characteristics and some poor ones	Checking the objective function—ensure proper scoring. Adjust constants, or adjust linearity of the measure of quality (e.g., change a linear function to an exponential).
The fossil record shows many individuals that are violating constraints	Remapping the chromosome to allow most, if not all, possible individuals to meet constraints.
If all the above has been tried and the answer is still not optimal	Reorder the genes in the chromosome. Try using different variables or expressions for variables, e.g., instead of using X, use log X or 1/X. Combine variables in natural ways, e.g., if a problem is sensitive to a ratio X/Y, use X/Y and Y as a variables instead of X and Y. Try to make variables as robust as possible, with large valid ranges for the GA to work with.

Table 3.2: Parameter values for the Non-dominated Sorting Genetic Algorithm

NSGA-II	
Crossover	0.9
Mutation	$1/\nu$
Crossover Distribution Index	20.0
Mutation Distribution Index	100.0

ations are evaluated for the Yagi-Uda. In Chapter IV, the results from these runs are shown. These results are attained using the methods described in this chapter.

IV. Experimental Results and Analysis of Synthesized Antennas

Using the methodology found in Chapter III, antennas may be synthesized in an optimizing fashion that follows the principles of genetic operations and of antenna design explained in Chapter II. These resulting antennas may then be characterized and scrutinized for merit based upon their performance in the three areas of interest: mainlobe power gain, VSWR, and length along the antenna's main axis.

4.1 Experimental Design and Results

4.1.1 Experimental Design. The purpose of the LPDA and Yagi-Uda experimental design is to both minimize antenna structure size and maximize the power gain for that antenna, all while reducing the VSWR.

All runs in this study are executed with NEC4. This executable is unique and appropriate for more complicated antennas since there are more geometry and control commands available for NEC4, compared to NEC2 and NEC3. NEC4 is used to evaluate all antenna designs produced by the genetic algorithm. GNEC and 4NEC2, two graphical programs using NEC4 code, are enlisted for producing the diagrams in this research document. Runs are executed on a Pentium M processor 2.13 GHz with 2.00 GB of RAM. Run times range from two to six hours depending on the total amount of iterations. Frequencies of interest lie from 3 to 30 MHz. GNEC was instructed to evaluate performance at 3, 15, and 27 MHz, representing 10.7% of the frequency bandwidth when considering 1 MHz increments. Due to time limitations, nine runs were executed for the LPDA and four for the Yagi-Uda. A successful run is defined as the completion of the amount of antenna iterations, generations, and overall population associated with the particular task.

Each radiation pattern was evaluated by varying ϕ from 0° to 359° at 1° increments and θ was set to 90°. Equal weight was given to main lobe power gain, VSWR, and vertical length of antenna. Optimal, or at least improved, meant to increase the main lobe power gain at $\phi = 0$ while minimizing VSWR and antenna length.

Table 4.1: Results for Yagi-Uda antenna optimization compared to those of Lohn et al [41] (dB is measured at $\phi = 90°$, $\theta = 0°$)

Run	219 MHz		235 MHz		251 MHz	
	dB	VSWR	dB	VSWR	dB	VSWR
Lohn et al	10.34	2.57	10.58	2.02	10.51	1.70
1	55.24	10.06	50.71	2.99	44.68	2.31
2	16.70	1.44	17.95	1.19	18.81	1.71
3	36.40	4.29	35.84	3.77	34.79	3.83
4	48.77	7.97	49.55	1.61	53.00	1.20

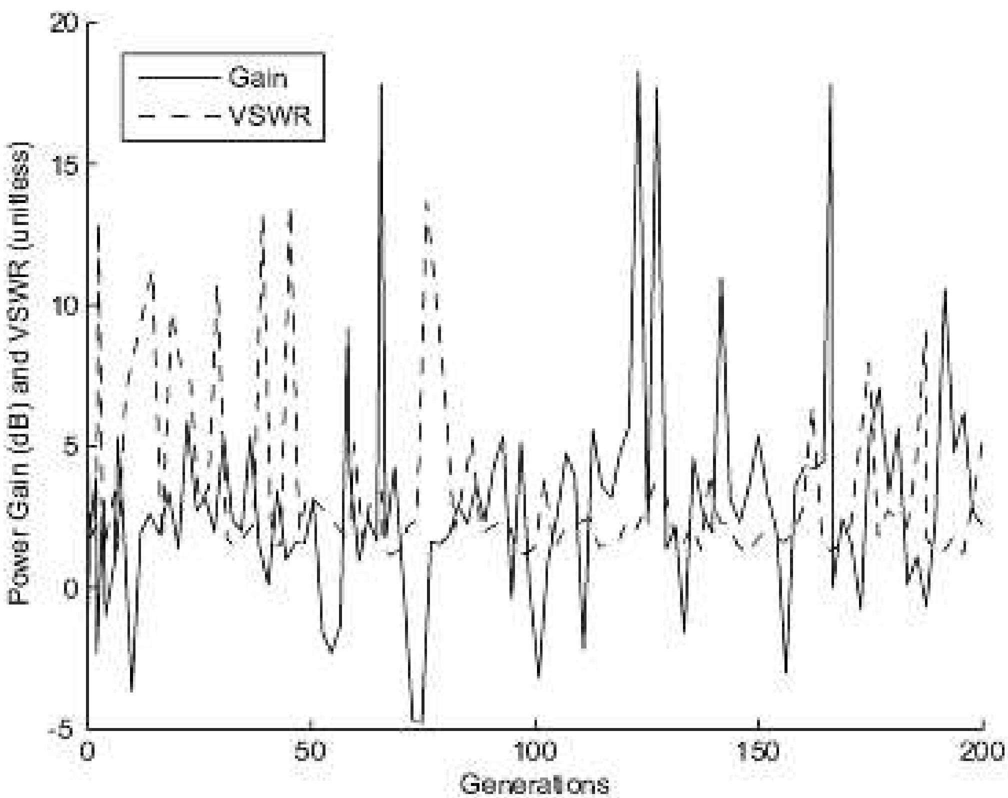


Figure 4.1: Design and simulation progress of Yagi-Uda antennas in run 4 (Best and worst results from each generation are taken and their Gain and VSWR are averaged)

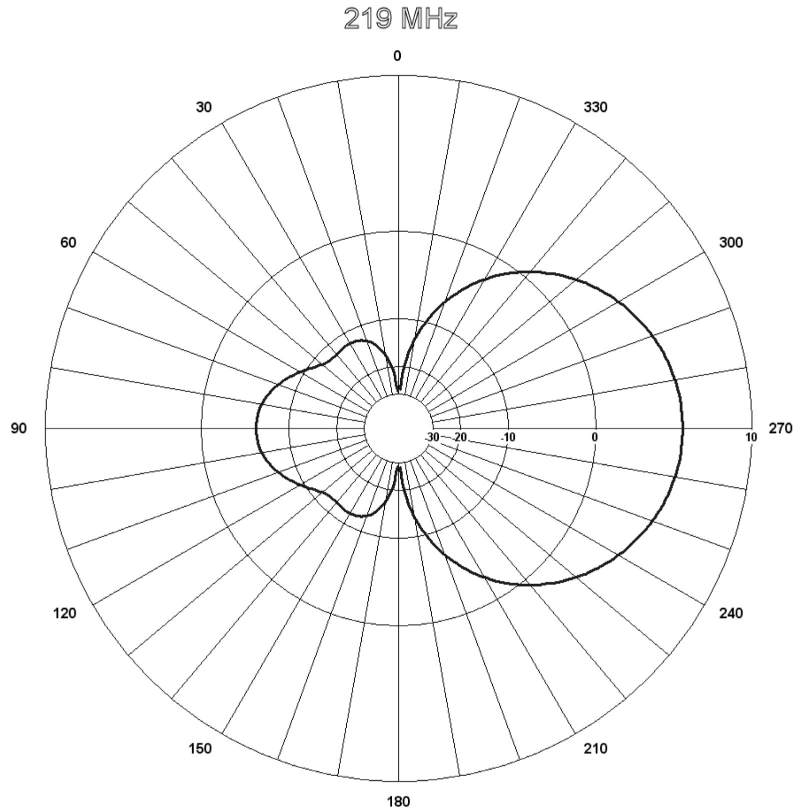


Figure 4.2: Radiation pattern at 219 MHz resulting from run 4 in evolving the Yagi-Uda antenna

Table 4.2: Results for LPDA antenna optimization while trying to minimize x, the vertical length (dB is measured at $\phi = 0°$, $\theta = 0°$)

	3 MHz		15 MHz		27 MHz	
Run	dB	VSWR	dB	VSWR	dB	VSWR
1	0.00	2.75	0.00	2.14	0.00	1.83
2	0.00	2.26	0.00	2.30	0.00	5.08
3	0.00	1.80	0.00	3.44	0.00	1.22
4	-23.88	5.75	0.00	1.06	0.00	3.47
5	-26.28	2.02	0.00	1.37	0.00	1.39
6	2.39	14.75	0.49	8.69	-2.75	1.88
7	0.00	2.50	0.00	4.17	0.00	8.27
8	0.00	7.66	-1.38	1.60	2.16	6.77
9	0.00	1.17	0.00	1.11	0.00	1.11

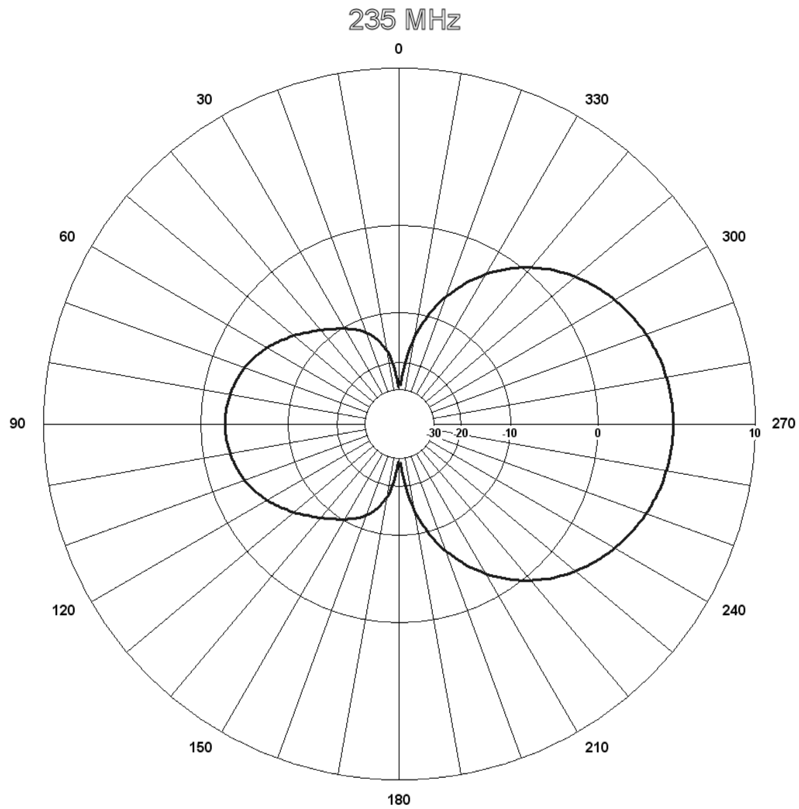


Figure 4.3: Radiation pattern at 235 MHz resulting from run 4 in evolving the Yagi-Uda antenna

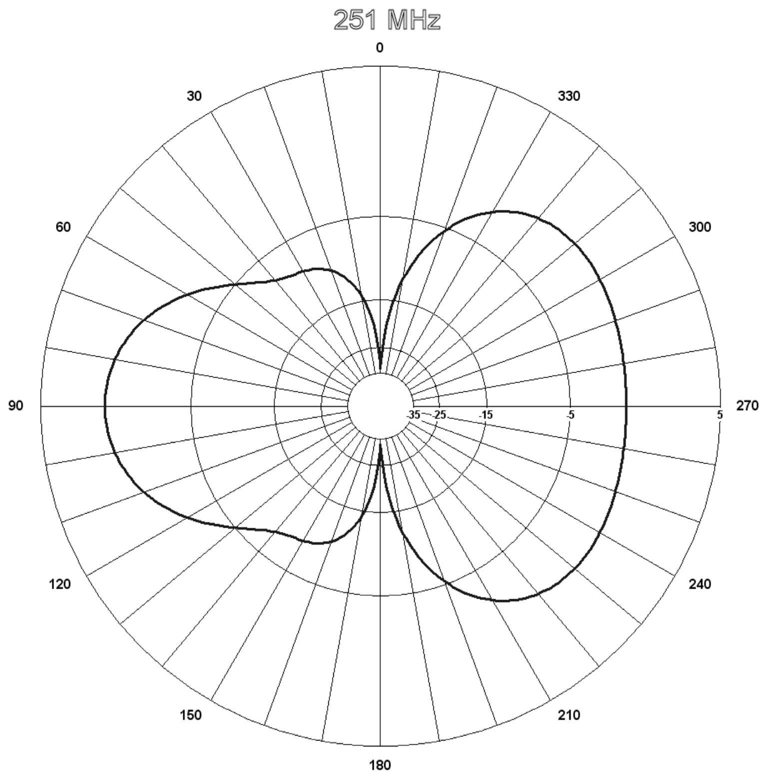


Figure 4.4: Radiation pattern at 251 MHz resulting from run 4 in evolving the Yagi-Uda antenna

4.1.2 Experimental Results.

4.1.2.1 Yagi-Uda. Results for Yagi-Uda antennas, following procedures in [41] (noted in section 4.1.1) indeed validate this antenna design process and are promising since better results are found. Reference Table 4.1 to compare this study's results with those of [41] by noting "Lohn et al". The convergence upon the objectives for the Yagi-Uda in run 4 is seen in Figure 4.1. This run was chosen as the best out of the four runs because of the average gain and average VSWR for all three frequencies. The associated radiation patterns for this run are in Figures 4.2, 4.3, and 4.4. The ending antenna and its specifications can be seen in Figure 4.5. The 3-D versions of the polar plots are seen in Figures 4.6, 4.7, and 4.8. A unique look at the interaction of an incoming electromagnetic wave with the antenna structure is portrayed through a visualization of both the phase and magnitude in Figure 4.9.

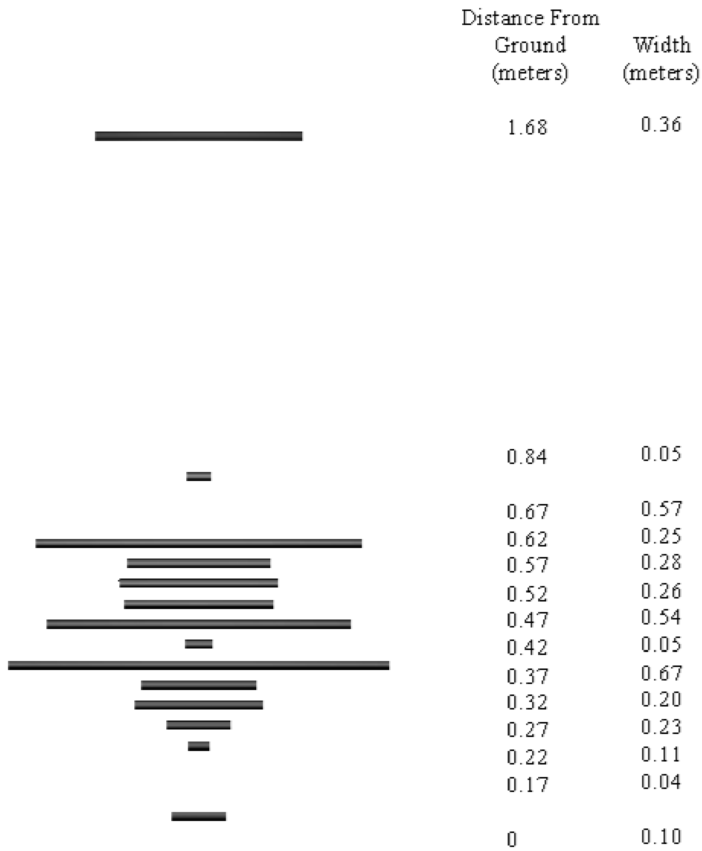


Figure 4.5: The Yagi-Uda structure from the best antenna in run 4. The radius of all elements is 1.5 mm.

Both the orientation and scale allow a unique look at the interactions for specific frequencies with the structure, in this case, 219 MHz.

4.1.2.2 LPDA. The results for iterating on the LPDA antenna are shown in Table 4.2. The results for the best run, run 9, are shown in the following figures. Figure 4.10 shows the convergence to the resulting antenna in run 9. The polar plots for this run are shown in Figures 4.11, 4.12, and 4.13 along with the 3-D plot for 15 MHz in Figure 4.14. The phase and magnitude interaction as it relates spatially to the antenna are depicted in Figure 4.15. The resulting structure and corresponding coordinates for run 9 are shown in Figure 4.16.

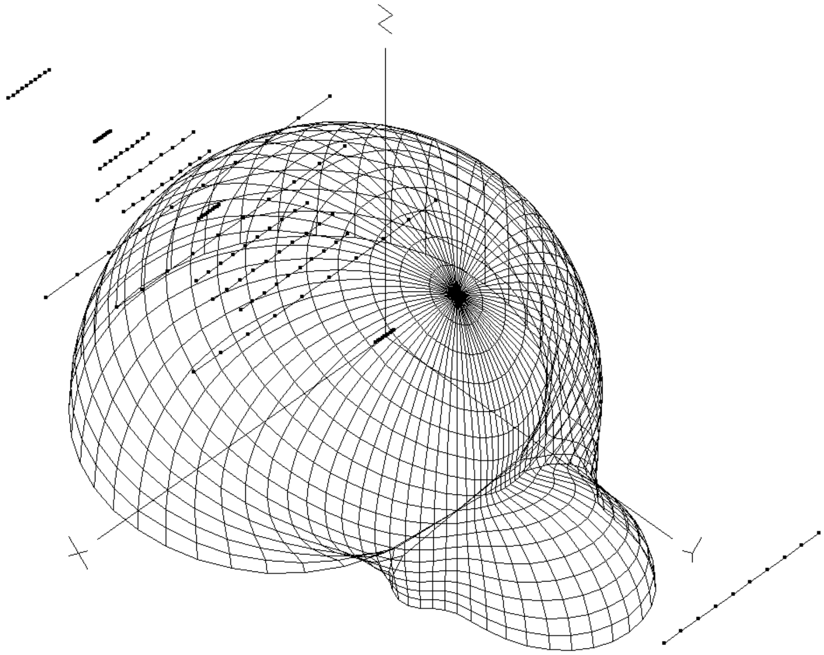


Figure 4.6: 3-D logarithmic power gain plot for 219 MHz resulting from run 4 in Yagi-Uda optimization.

4.2 Analysis of Antenna Design and iSIGHT Process

In this research, the overall objective is to design, analyze, and discover a *best* run out of several variations both for the Yagi-Uda and LPDA. This is based upon the antenna's main lobe power gain, VSWR, and length where both VSWR and length are minimized while maximizing the antenna's main lobe power gain at the angles of $\theta = 0$ and $\phi = 0$.

The resulting structure from the Yagi-Uda runs is only 1.68 meters in length. That is less than $1/3$ of the allowed space. The resulting LPDA structure is less than half the allowed length at 29.57 meters. In run 4 for the Yagi-Uda, the power gain at 251 MHz is 53.00 dB with a VSWR of 1.20; this is more than 500% of the reported 10.51 dB gain noted in [41] for the same frequency and has a 0.50 decrease in VSWR.

The results for the LPDA are not as promising once antenna patterns are looked at for all azimuth angles, ϕ. At 27 MHz in particular, it is obvious that sidelobes were not minimized at 135° and 180°. Though this was an objective, it is clear that

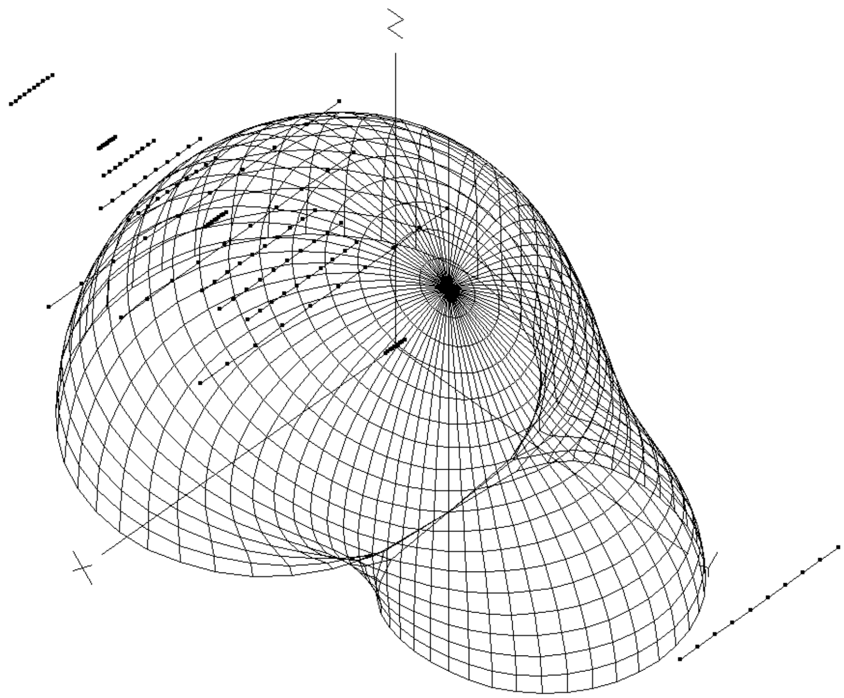


Figure 4.7: 3-D logarithmic power gain plot for 235 MHz resulting from run 4 in Yagi-Uda optimization.

the algorithm saw the trade-off for the amount of gain as favorable. The VSWR is certainly a remarkable improvement as it nears the nominal value of 1.0 for all three frequencies. This, combined with the power gain for all frequencies combine to a well-rounded, broad-band antenna.

The inclusion of requirements for sidelobes and backlobes did not facilitate improvement in the main lobe as much as anticipated for 27 MHz. This is seen clearly in 4.13. The increased computation time is unknown; however, the addition of a ground plane and its variations would be a unique addition to this study. In addition to adding improved main lobe gain and reduced backlobe and sidelobe gain, the ground plane would allow the GA more design space and would be suited for much larger populations and generations and, though it would increase the computation time, it would be beneficial for producing a directional LPDA. The discussion on why to exclude backlobe and sidelobe criteria in the cost function, cited in [41], assumes minimization of power gain at desired angles (because of maximization in

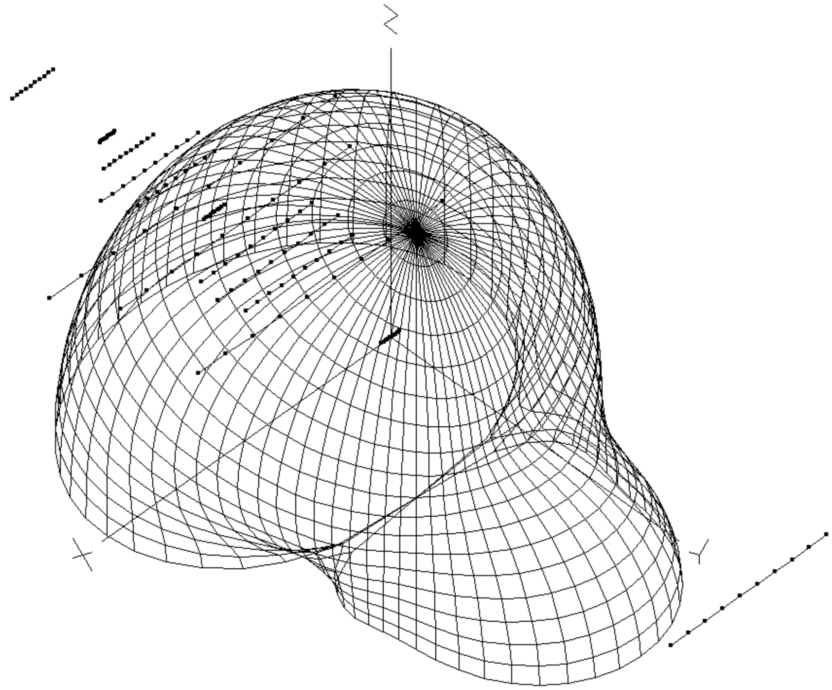


Figure 4.8: 3-D logarithmic power gain plot for 251 MHz resulting from run 4 in Yagi-Uda optimization.

the main lobe) but may be presumptuous when designing LPDAs as results in this study suggest.

Figure 4.9: Phase and magnitude of received/transmitted electromagnetic signal with relation to spatial location.

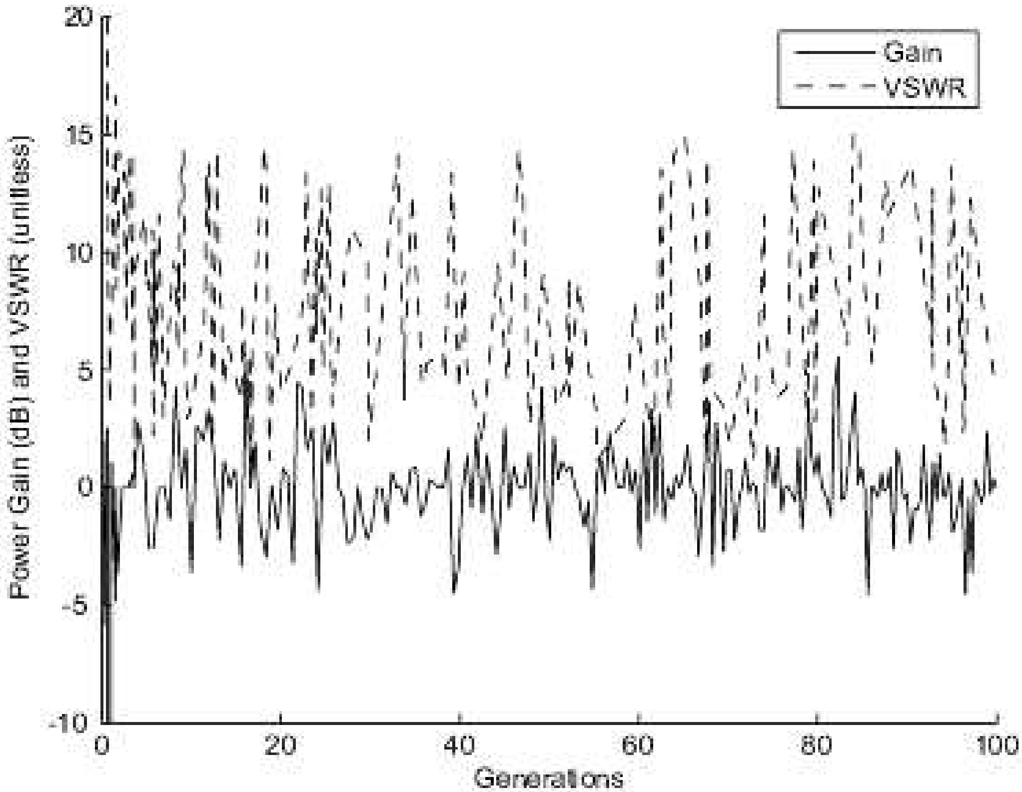


Figure 4.10: Design and simulation progress of LPDA antennas in run 9 (Best and worst results from each generation are taken and, separately, their Gain and VSWR are averaged).

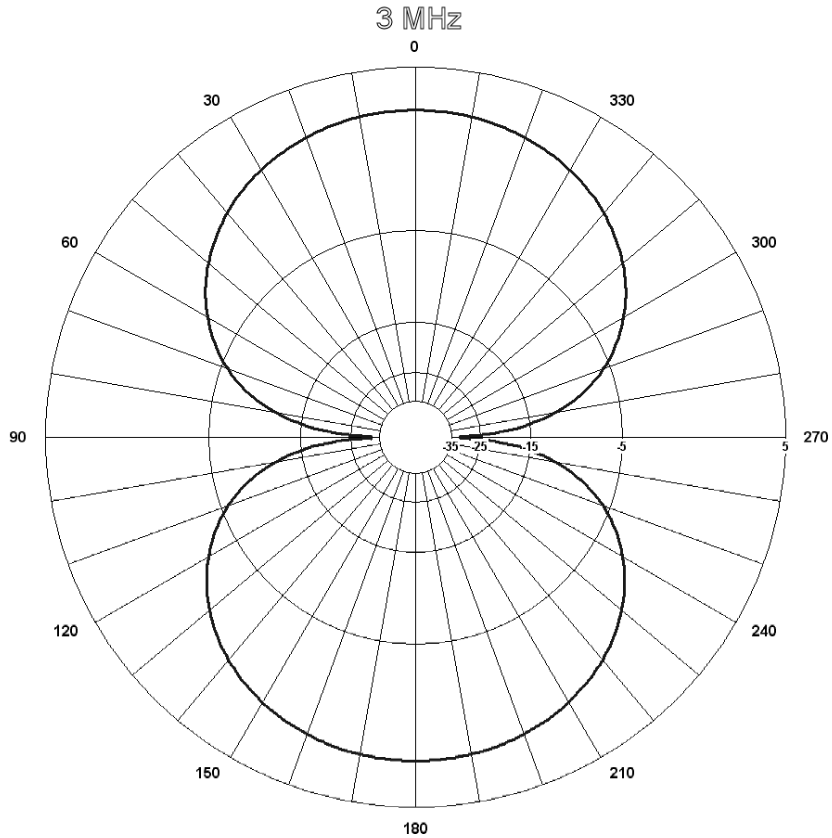


Figure 4.11: Radiation pattern at 3 MHz resulting from run 9 in evolving the LPDA antenna showing a backlobe of the same size as the mainlobe

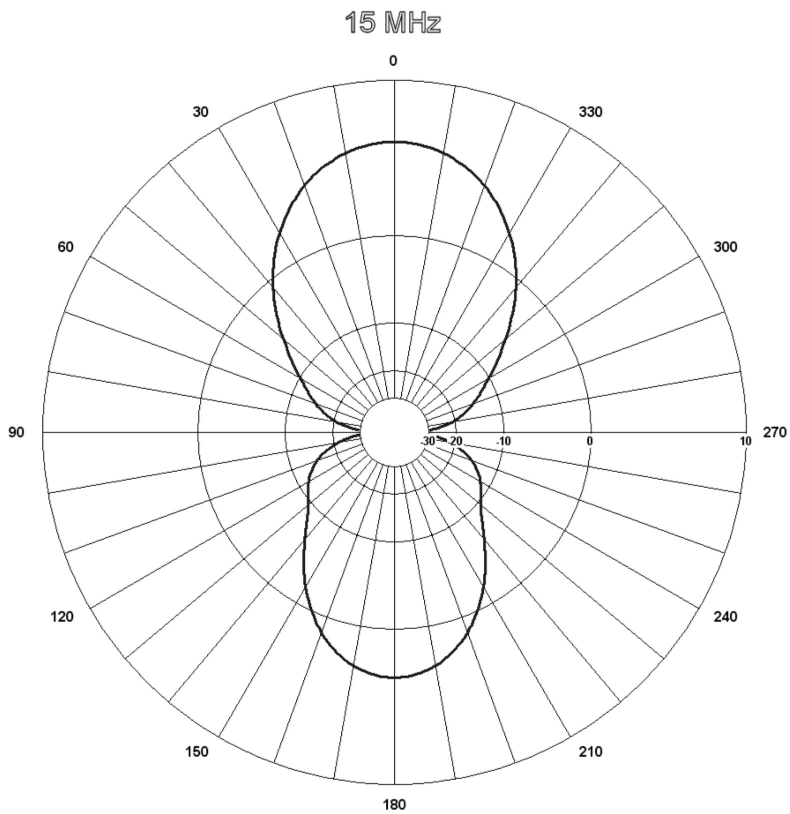


Figure 4.12: Radiation pattern at 15 MHz resulting from run 9 in evolving the LPDA antenna showing reduced backlobe compared to the 3 MHz pattern

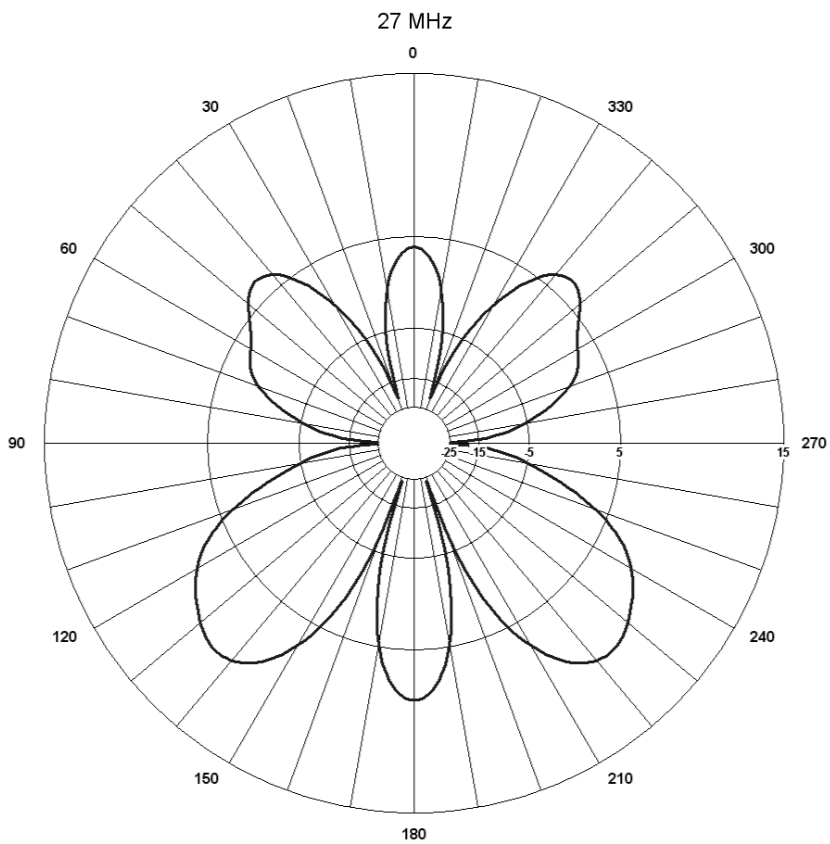


Figure 4.13: Radiation pattern at 27 MHz resulting from run 9 in evolving the LPDA antenna

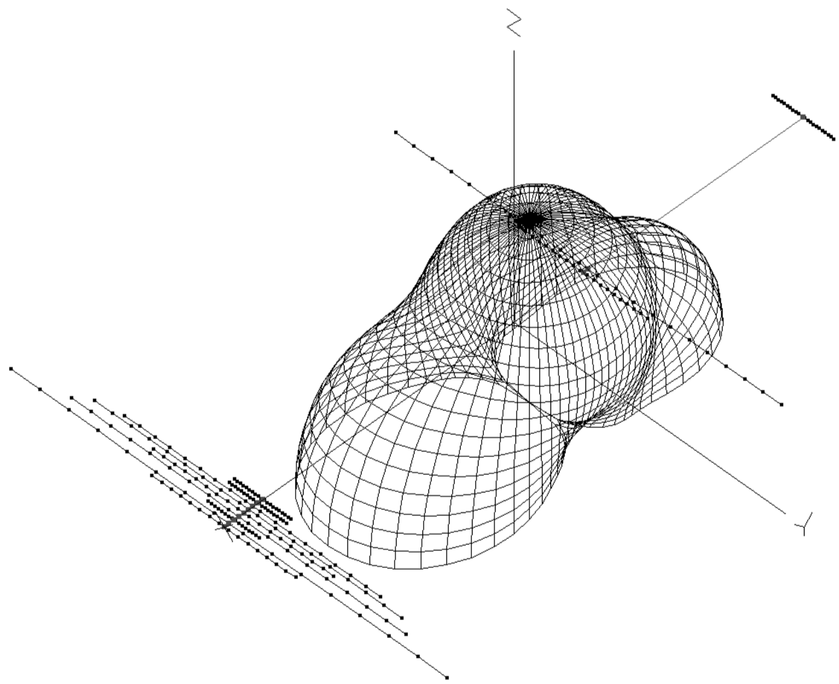


Figure 4.14: 3-D logarithmic power gain plot for 15 MHz resulting from run 9 in LPDA optimization

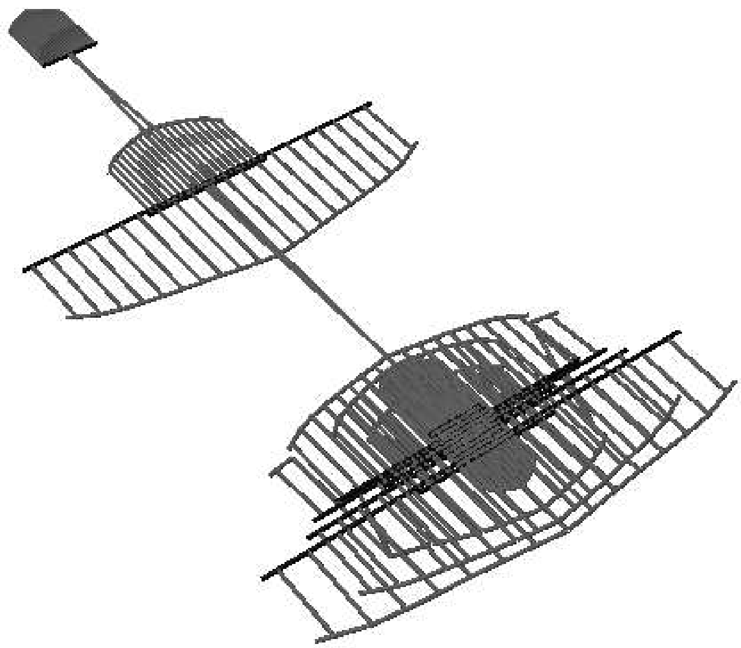
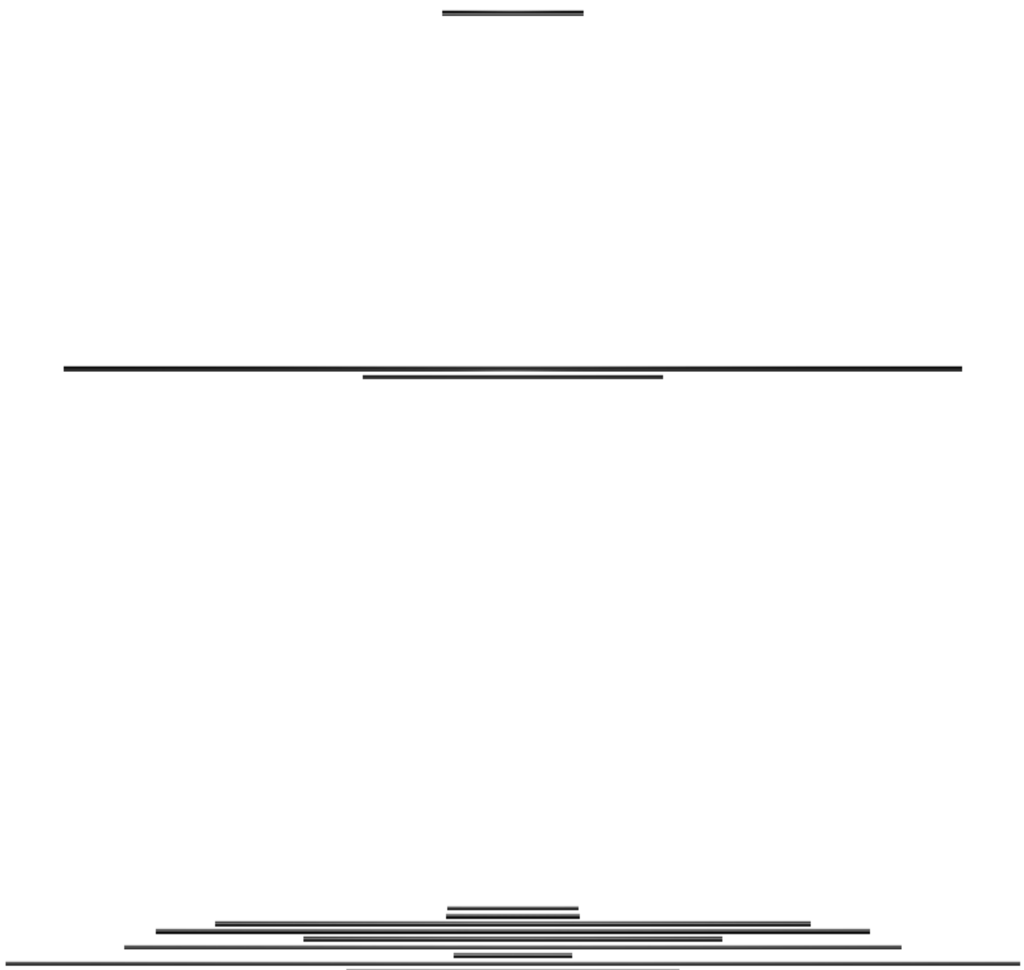


Figure 4.15: Phase and magnitude of received/transmitted electromagnetic signal with relation to spatial location



Distance From Ground (meters)	Width (meters)
0	3.13
10.97	19.69
11.22	6.60
27.60	2.90
27.85	2.91
28.10	13.05
28.32	15.66
28.57	9.18
28.82	17.03
29.07	2.62
29.32	22.23
29.57	7.32

Figure 4.16: The LPDA structure from the winning antenna in run 9. The radius of all elements is 3.5 cm.

V. Conclusions

This thesis presents a computational process for antenna optimization and describes how to reproduce that computing package with detail. The process is validated by the reproduction of and improvement upon previous work in Yagi-Uda antennas found in [41]. The process is then extended to LPDA antennas and the results documented.

The major achievement in this research is the contribution of the computational process and package of GNEC and iSIGHT that is both valid and reproducible. The combination of these two software packages is invaluable because of how they may be used to produce improvements on existing antenna structures that are not covered in this research document. This may be accomplished with ease through the aid of Appendix A. This tool may prove useful for future work in many applications. Some of the particular areas that are of interest to the AFRL are in satellite antennas, simple signal reconnaissance, both overt and covert, and signal transmission in land and air applications. It may also be used for conformal array antennas which greatly aid the implementation of both aeronautical and low observable technologies.

The improvements made in the Yagi-Uda antenna validate this computational process and package. With regards to the LPDA results, even small improvements can lead to significant changes in abilities for various antenna applications. These trials developed several interesting antennas in a time-efficient manner. Placing larger constraints and more objectives for particular applications could extend computation time but would yield a realizable antenna that could ease signal processing requirements. With the addition of a ground plane behind the antenna, the gain could improve and these antennas could be more suited for detecting low power signals.

The applied GA worked well but the use of other models of evolutionary algorithms (such as those listed in Section 2.4) could be employed to search for different results. The use of a single objective algorithm could be equally viable and perhaps decrease computation time. This could lead to a newer approach that might exceed the performance of this implementation.

Constraining designs in the LPDA optimization runs to remain either exclusively log periodic or very close to LPDA design would be an area where further work would be viable. This constraint could lead to greater directivity while keeping a very broadband antenna since LPDA are naturally directive. This could be accomplished by varying two elements, defining τ and α as seen in Subsection 2.7.6 based upon those two elements, and then building an antenna with a varying amount of other elements, all of which are conformal to the constraints imposed by the variables τ and α. Leniency could be allowed in the degree to which the remaining elements conform to the constraints allowing the model to not remain strictly log periodic.

Imaginary numbers in this research were impossible to calculate and use in iSIGHT. There is a toolbox that can be added to iSIGHT 9.0 which handles imaginary numbers. This toolbox, though more expensive, would greatly complement antenna optimization and the calculation of VSWR as well as phase and overall antenna characterization. It may be procured through [16].

Finally, it is encouraging to continue pursuing optimized antennas as more is required from the design and simulations, adding to the new and already robust techniques of antenna optimizations through the use of GAs.

Appendix A. How to Use GNEC inside of iSIGHT

These are the steps needed for creating an optimization run inside iSIGHT. They are presented in rudimentary form so that common mistakes may be avoided in setting up a Task inside iSIGHT. The goal here explain thoroughly the capabilities of iSIGHT; that would only repeat information in many manuals available for such tasks. Here is presented a most easy, though not intuitive, approach for incorporating GNEC inside of iSIGHT.

The support staff at Engineous Software is most helpful and, though incorporating GNEC as the slave of iSIGHT involved weeks of work, the eventual success attained may be largely attributed to that support staff. Thus, this step-by-step procedure is presented here to both complement future work in antenna optimization and other optimization studies as well as save frustrations whose roots are quite simple.

! When creating the parent directory in which folders and files associated with iSIGHT runs it is best to place it on as its own parent folder in your data drive (e.g. C: or D:). The reason is that if any file, folder, or directory directory contains spaces or special characters (e.g. "#, $, %" etc), then iSIGHT will return an error. This is further addressed later in this appendix but useful knowledge when trying to avoid an early mistake.

- Open iSIGHT
- Go to File/New
- Click on Simcode in the icon bar (see Figure A.1)
- Double click on the box that pops up labelled Simcode0
- For Input0, click on the Input Properties (pink box next to Input0) as shown in Figure A.2
- Click on File and navigate to the *.nec* file that you wish to run in GNEC
- If it asks you if you wish to place the description file in this same directory and that is satisfactory for you, then go ahead and do so. You may wish to create a

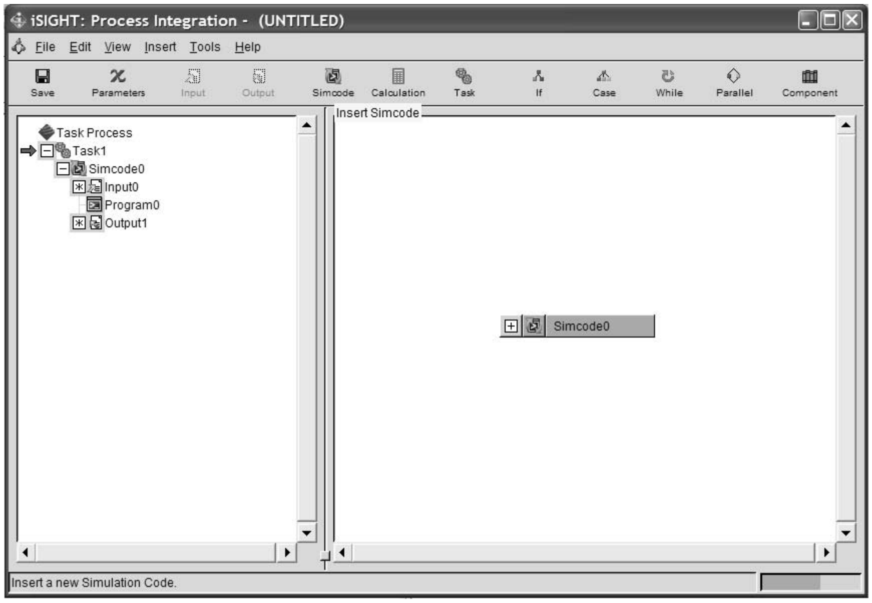


Figure A.1: Starting a Simcode in iSIGHT

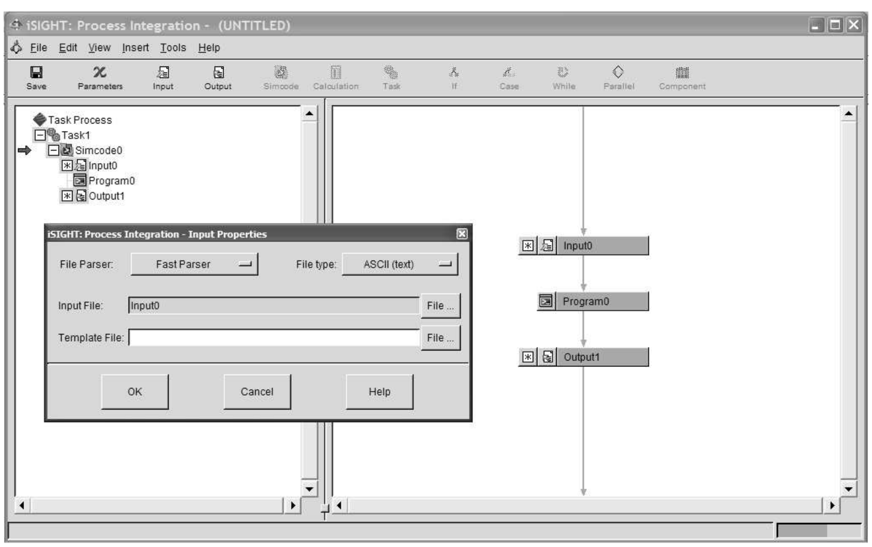


Figure A.2: Setting the Input parameters as well as pointing to the appropriate files for Process Integration

folder that holds all files for this iSIGHT run and name it and all associated file uniformly and uniquely. This may prove helpful when processing the results of several different optimization runs

- If you have not already created a template file, iSIGHT will ask you if it can create one for you, click yes.
- Click "OK" and you will be returned to iSIGHT's Process Integration window
- For Output0, click on the Output Properties (pink box next to Output0) as shown in Figure A.3

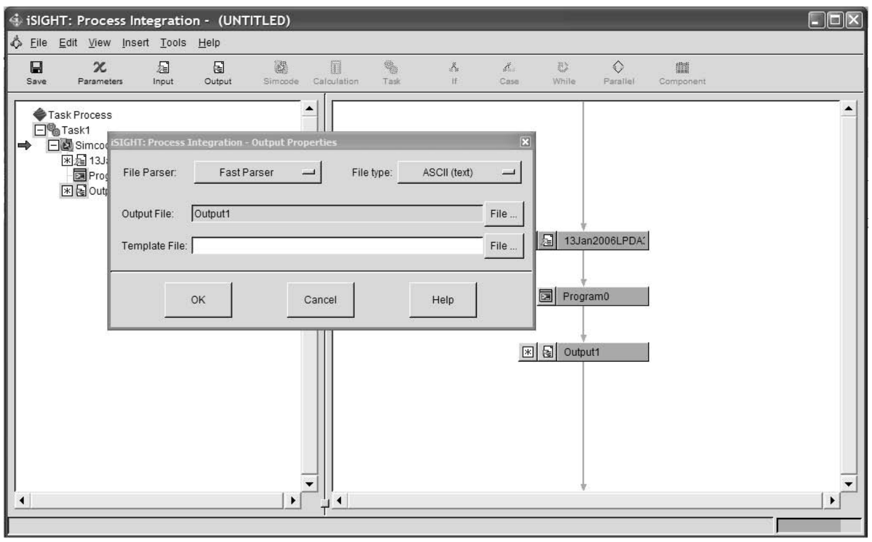


Figure A.3: Setting the Output parameters as well as pointing to the appropriate files for Process Integration

- Go through a similar procedure only this time you are looking for the .nou output file associated with the *.nec* input file sited in Input0. (Note: If you have not run the *.nec* file inside of GNEC then this would be an appropriate time to do so that GNEC will create the associated output file)
- When prompted about the creation of a template, click "Yes" and then "OK" so as to return to the Process Integration Window
- Note that both Input and Output Properties boxes are no longer pink

- Now it is time to define input and output parameters:
- You will note that Input0 has now been renamed the first part of your *.nec* and .nou file
- Click on Input Contents for the first box, the input box. This also is pink (See Figure A.4)

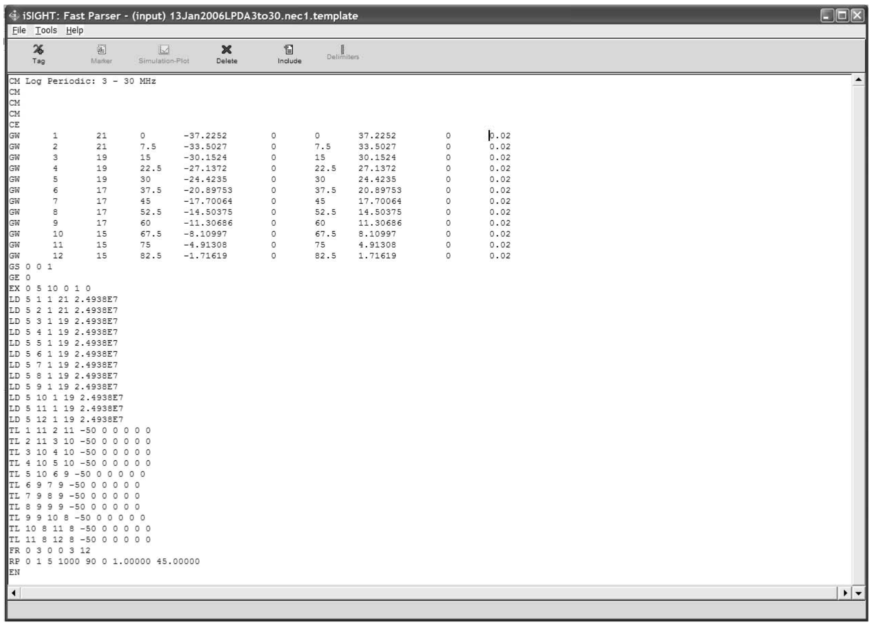


Figure A.4: Setting the input parameters in Process Integration

- This process is called tagging and is done in several ways:
- Double click on the value you wish to define as a variable and click the Tag icon in the icon bar. This can be seen in Figure A.5

- Name the variable
- Define the substitution type (choices are: scalar, array element, array column, or multiple values)
- Scalar is useful for single value non-array variables
- Array Element is useful for arrays that do not fall in order in the output file

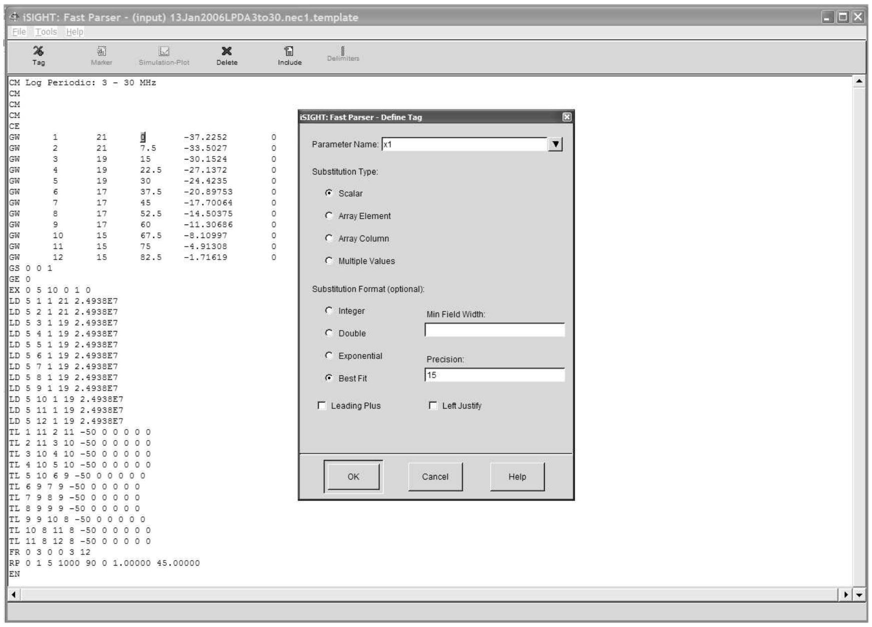


Figure A.5: Tagging a specific variable as an input parameter

- Array Column is a quick way to define many Elements to an Array when they are in column fashion in the output file
- Multiple Values may be used when you would like to substitute the same number into many Variables
- Define the Substitution Format (self explanatory) and Width and/or the precision associated with it.
- Click "OK" o Repeat this process as many times as needed for your different variables
- Click on Output Contents for the Output box. This also is pink
- Similarly, Tag any output parameters that are of interest as shown in Figure A.6. These outputs will become the focus for iSIGHT in its endeavor to optimize your model.

- Lastly for Process Integration, click on the last pink box, the one next to Program0 as seen in Figure A.7

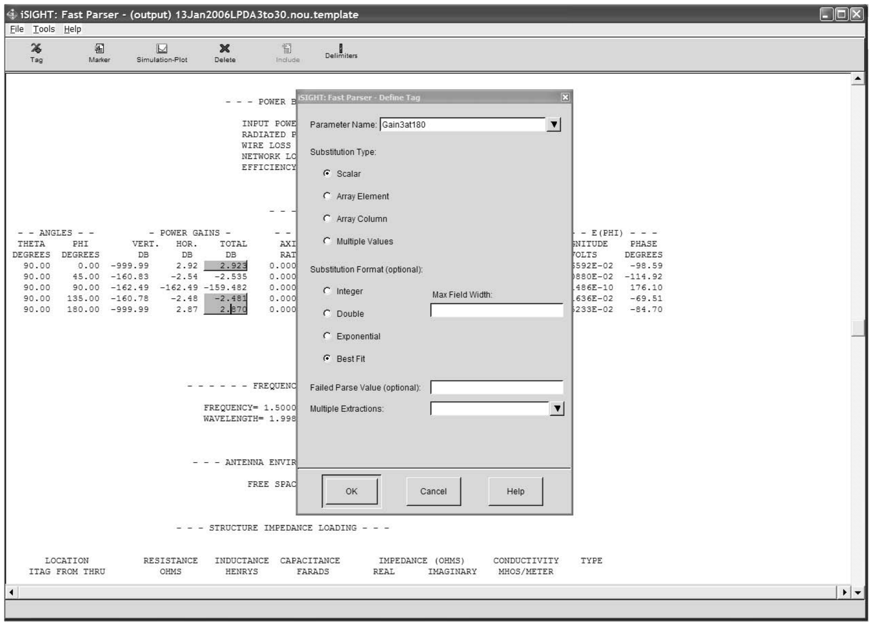


Figure A.6: Opening the output file and tagging output parameters in Process Integration

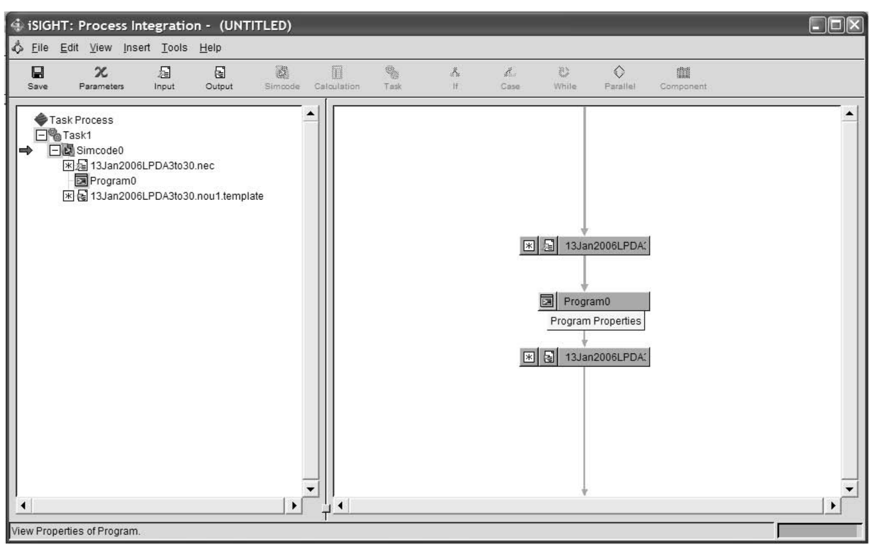


Figure A.7: Opening the program execution interface inside Process Integration

- For GNEC, we want to run the executable from the Command Line. To do this we need to change the "Type:" from Executable to Script as shown in Figure A.8 and then proceed to write that script described in Figure A.9.

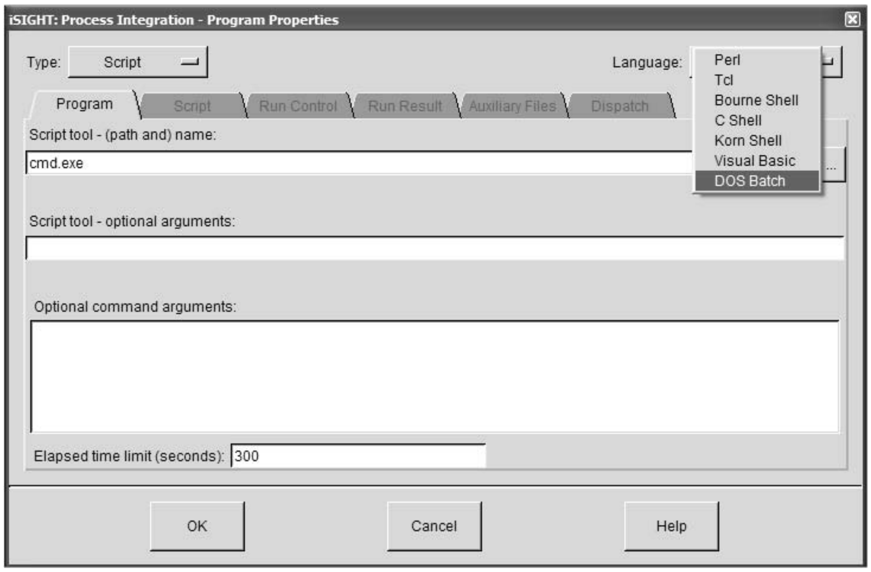


Figure A.8: Setting the executable needed for program execution inside the DOS Batch Program for Process Integration

- Once Script has been chosen, another box pops up that says "Language," choose DOS Batch

- Go to the Program Tab and ensure that "*cmd.exe*" is in the Script tool - (path and) name bar.

- Taylor the Elapsed time limit (seconds) bar to what you wish (default is 5 minutes or 300 seconds)

- Click the Script Tab and input a variation of the following example seen in Figure A.9 according to your own file structure. Here it shows the commands that point to items in the C: drive such as the the "*.nec*" "*lpda19to29.nec* " in "*isightfiles* \ *lpda19to29*" or the GNEC executables in "GNEC16 \ bin". Ensure that there is a "hard return" after "exit" as depicted by the cursor in the Figure. If this is absent then the command "exit" will not be executed.

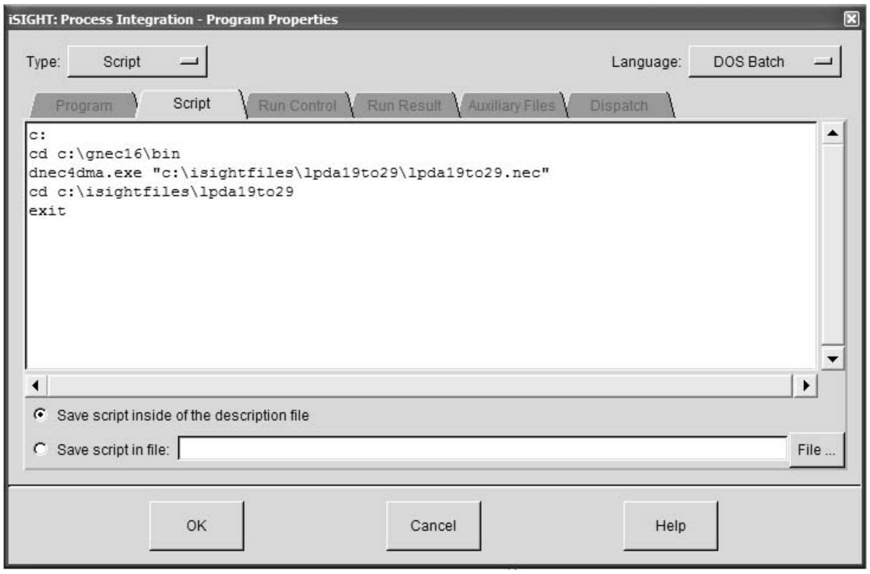


Figure A.9: Writing the script needed for program execution inside the DOS Batch Program for Process Integration

- iSIGHT requires that no spaces are in any of the folers or file names and, in this example, I have placed my important files in a folder called isightfiles, right inside of the c:. This ensures that I have control over the names of all the parent folders to my specified input file.
- *dnec4dma.exe* is the executable for NEC4, inside of GNEC. If you choose to use NEC2, the executable associated with it is also in the same directory. It's file name is *NEC32.exe*
- Once this has been done, you may click "OK" and iSIGHT will return you to the Process Integration Window
- Go to File and click Save(needed). If you have not yet named the description file, iSIGHT will prompt you inside the folder containing the input and output files from GNEC. Keep the description file in this same folder to avoid complications
- iSIGHT will then ask to rescan the file before saving. Click "Yes," as this is a way to detect mistakes in the setup just implemented
- Assuming no errors are detected, go to File and click Close

- You are taken back to the Task Manager Window. In here we will need to define the boundary conditions for the Parameters and the objectives for the output(s) as well as create a Task Plan that iSIGHT will follow

- First we look at the Parameters.

- Click on the Parameters icon in the icon bar. Define the boundary conditions for the all inputs. Define the objective for the outputs (nothing, minimize, maximize) by clicking on the box two columns away from the name as seen in Figure A.10.

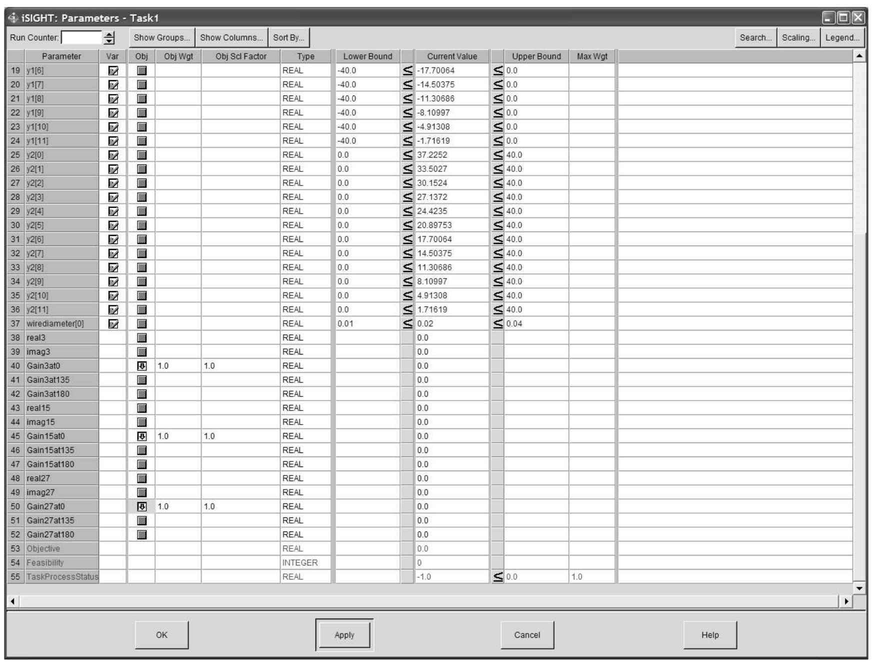


Figure A.10: Defining boundary conditions and objectives for inputs and outputs inside the Parameters window

- Ensure that no boxes are highlighted pink. This would indicate that an infeasible condition has been requested

- Click “Apply” and then “OK”

- Now we’ll look at Task Plan

- Click on the Task Plan icon in the icon bar. You may use the default (Optimization: *Advisor* PriorityRankedPlan) or you may create a new Task Plan as shown in Figure A.11.

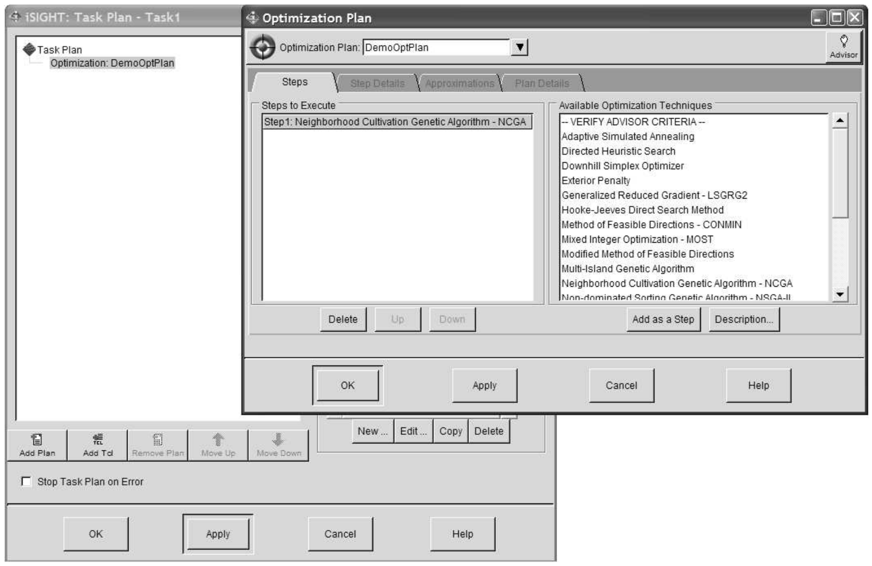


Figure A.11: Defining an optimization method inside the Task Plan

- To create a new Task Plan, click the "New" box located in List of Existing Plans.
- From here you may choose from a myriad of techniques, the scope of which surpasses this tutorial. Note that a description for each technique is available under the scroll menu in the technique box
- Once the technique is chosen, select "Add as Step", click "Apply" and then "OK"
- Once back in the Task Plan window, select the newly made Plan and click "Add Tcl" in the adjacent box. After this has been done the "Remove Plan" icon becomes available. Select any unwanted technique plans and use this icon to remove them.
- Once all is appropriately setup, click "Apply" and then "OK"

- Once you are at this point, there is a good number of ways to continue. If everything is setup properly, you execute the run, but in order to monitor it I'll suggest these few things.
- First change the Run Mode to "Single" instead of "Task Plan" as seen in Figure A.12. Click the green ball icon which is the Execute button. If you're description file is setup correctly, this will execute in a few seconds. If it is not setup correctly then you will have to wait for that (300 second default) time limit to be reached and the run will fail but still give you the results that it tried to come up with. Either way, this is a good way to ensure that everything is working properly. Once success is reached, put Run Mode back into the Task Plan mode.

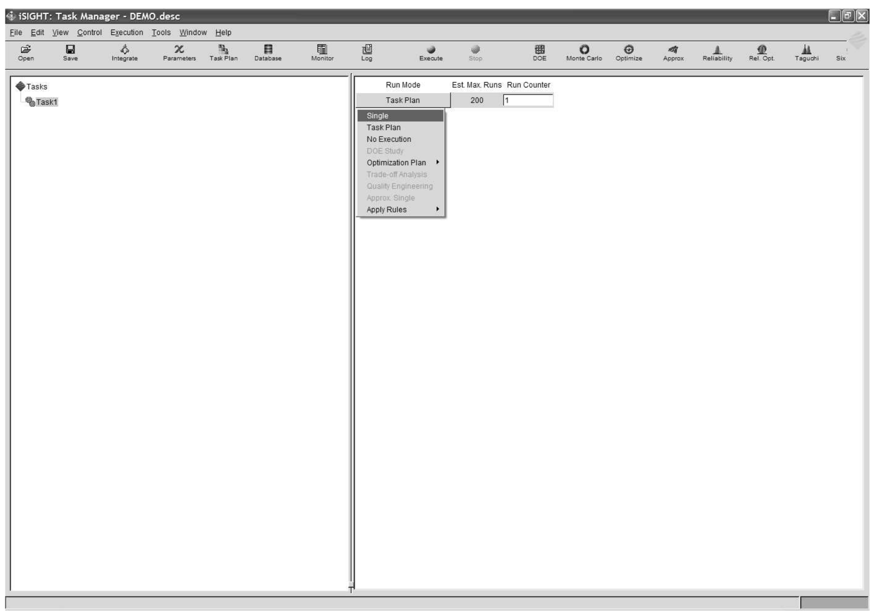


Figure A.12: Before running the Task Plan, set the execution method to Single for evaluating the execution's viability

- Click the Monitor icon in the icon bar. This will setup a visual monitoring window that you can tailor to your monitoring needs. Common is the Table icon from which you can create a Custom table after clicking "OK." If you right-click on this you can select "Fit to Window," allowing the table to be much more easily read.

- This and other graphs could prove useful in watching the results as they unfold.
- Last thing to do before you click on execute is to ensure the Log is showing by clicking on the "Log" icon in the icon bar. This will come up automatically but experience has taught that viewing this and paying close attention to the errors or warnings generated are key to finding a bug early. This will alert you to timed-out executions as well as give you additional information concerning the progress of the run.
- Don't leave the solution monitor on during the execution of the optimization plan. Although it helpful at first to ensure that the program is running correctly as it progresses, it severely increases run times. A run that can be accomplished in four hours would complete only after 48 hours, if then. Any need for graphs or data can be constructed post-execution by going to the *Task1.db* text file that is created during each run and drawing from it the columns or rows of data that is needed.
- Now you're ready to run your optimization plan!

Appendix B. GNEC Code

In this appendix, examples of GNEC code are given for a Dipole, a Disc Cone, a Yagi-Uda, and Log Periodic Dipole Arrays. Some of the included examples are from [19]. These antennas are viable starting points for optimization within iSIGHT.

B.1 Dipole

Listing B.1: An example of a Fat Dipole.(appendix2/fatdipole.nec)

```
CM fat_dipole
CM TITLE A Fat Dipole TITLE
CM a fat half-wave dipole at 98MHz, 8" thick, shortened by .2
CE
GW 1 9 0.0 -.665 0.0 0.0 .665 0.0 0.1
GE
EX 0 1 5 0 1.0
FR 0 41 0 0 80.0 1.0
RP 0 91 91 1110 90.0 0.0 4.0 4.0
XQ
EN
```

B.2 Two Dipoles on a Roof

Listing B.2: An example two dipoles on a roof.(appendix2/2dipoleonroof.nec)

```
CM Example file by Dimitry Fedorov, UA3AVR
CE
GW 1 39 0 -2.55803 7.1 0 2.55803 7.1 0.008
GW 2 39 0 -2.55803 0 0 2.55803 0 0.008
GM 0 0 0 0 90 0 0 1.5 0
GW 3 20 -10 -7 -3 10 -7 -3 0.001
GW 4 20 -10 -6 -2.57143 10 -6 -2.57143 0.001
GW 5 20 -10 -5 -2.14286 10 -5 -2.14286 0.001
GW 6 20 -10 -4 -1.71429 10 -4 -1.71429 0.001
GW 7 20 -10 -3 -1.28571 10 -3 -1.28571 0.001
GW 8 20 -10 -2 -0.85714 10 -2 -0.85714 0.001
GW 9 20 -10 -1 -0.42857 10 -1 -0.42857 0.001
GW 10 20 -10 0 0 10 0 0 0.001
GW 11 20 -10 1 -0.42857 10 1 -0.42857 0.001
GW 12 20 -10 2 -0.85714 10 2 -0.85714 0.001
GW 13 20 -10 3 -1.28571 10 3 -1.28571 0.001
GW 14 20 -10 4 -1.71429 10 4 -1.71429 0.001
GW 15 20 -10 5 -2.14286 10 5 -2.14286 0.001
GW 16 20 -10 6 -2.57143 10 6 -2.57143 0.001
GW 17 20 -10 7 -3 10 7 -3 0.001
GW 18 7 -10 -7 -3 -10 0 0 0.001
GW 19 7 -9 -7 -3 -9 0 0 0.001
GW 20 7 -8 -7 -3 -8 0 0 0.001
GW 21 7 -7 -7 -3 -7 0 0 0.001
GW 22 7 -6 -7 -3 -6 0 0 0.001
```

```
GW 23 7 -5 -7 -3 -5 0 0 0.001
GW 24 7 -4 -7 -3 -4 0 0 0.001
GW 25 7 -3 -7 -3 -3 0 0 0.001
GW 26 7 -2 -7 -3 -2 0 0 0.001
GW 27 7 -1 -7 -3 -1 0 0 0.001
GW 28 7 0 -7 -3 0 0 0 0.001
GW 29 7 1 -7 -3 1 0 0 0.001
GW 30 7 2 -7 -3 2 0 0 0.001
GW 31 7 3 -7 -3 3 0 0 0.001
GW 32 7 4 -7 -3 4 0 0 0.001
GW 33 7 5 -7 -3 5 0 0 0.001
GW 34 7 6 -7 -3 6 0 0 0.001
GW 35 7 7 -7 -3 7 0 0 0.001
GW 36 7 8 -7 -3 8 0 0 0.001
GW 37 7 9 -7 -3 9 0 0 0.001
GW 38 7 10 -7 -3 10 0 0 0.001
GW 39 7 -10 0 0 -10 7 -3 0.001
GW 40 7 -9 0 0 -9 7 -3 0.001
GW 41 7 -8 0 0 -8 7 -3 0.001
GW 42 7 -7 0 0 -7 7 -3 0.001
GW 43 7 -6 0 0 -6 7 -3 0.001
GW 44 7 -5 0 0 -5 7 -3 0.001
GW 45 7 -4 0 0 -4 7 -3 0.001
GW 46 7 -3 0 0 -3 7 -3 0.001
GW 47 7 -2 0 0 -2 7 -3 0.001
GW 48 7 -1 0 0 -1 7 -3 0.001
GW 49 7 0 0 0 0 7 -3 0.001
GW 50 7 1 0 0 1 7 -3 0.001
GW 51 7 2 0 0 2 7 -3 0.001
GW 52 7 3 0 0 3 7 -3 0.001
GW 53 7 4 0 0 4 7 -3 0.001
GW 54 7 5 0 0 5 7 -3 0.001
GW 55 7 6 0 0 6 7 -3 0.001
GW 56 7 7 0 0 7 7 -3 0.001
GW 57 7 8 0 0 8 7 -3 0.001
GW 58 7 9 0 0 9 7 -3 0.001
GW 59 7 10 0 0 10 7 -3 0.001
GM 0 0 0 0 -90 0 0 28 0
GS 0 0 1.0
GE 1
GN 2 0 0 0 30 0.001
FR 0 1 0 0 28.05 1
TL 1 20 2 20 50 10.69518717
EX 0 2 20 0 0.5000 0.0000
'RP 0 1 360 1000 85 0 0 1
RP 0 181 1 1000 90 0 -1 0
EN
```

B.3 Panel

Listing B.3: An example of a panel antenna.(appendix2/panel.nec)

```
CM NEC Input File Panel_2x2 for 2442 MHz, Pow 20020706 |
```

```
CM Frequency range 2412..2472 MHz                         |
CM   + 14 dBi gain, f/b ratio 18 dB                       |
CM   + 40 deg horiz, 30 deg vertical 3 dB beamwidth       |
CM   + SWR < 1.3                                          |
CM All data in wavelengths. Scaled to meters with GS      |
CM ----------------------------[ http://pow.za.net/ ]--'
CE
SY  W=.006            ' Wire radius
SY Rx=1.5/2, Rnx=5    ' Reflector width / 2
SY Ry=1.5/2, Rny=5    ' Reflector height / 2
SY Dl=.25             ' Dipole arm length
SY Dh=.22             ' Dipole height over reflector
SY Dx=.38             ' Distance between left and right dipole / 2
SY Dy=.38             ' Distance between top and bottom dipole ...
   centers / 2
GW 1 1 Dh 0. W Dh 0. -W W
GW 2 31 Dh Dx -Dl-Dy Dh Dx Dl-Dy W
GW 3 31 Dh -Dx -Dl-Dy Dh -Dx Dl-Dy W
GW 4 31 Dh Dx -Dl+Dy Dh Dx Dl+Dy W
GW 5 31 Dh -Dx -Dl+Dy Dh -Dx Dl+Dy W
SM Rnx*2 Rny*2 0. -Rx -Ry 0. Rx -Ry
SC 0 0 0. Rx Ry
GS 0 0 300.0/2442.0
GE 0
TL 1 1 2 16 50. 0. 0. 0. 0. 0.
TL 1 1 3 16 50. 0. 0. 0. 0. 0.
TL 1 1 4 16 50. 0. 0. 0. 0. 0.
TL 1 1 5 16 50. 0. 0. 0. 0. 0.
EX 0 1 1 0 1. 0
FR 0 1 0 0 2442. 0
RP 0 73 73 1001 -90. 90. 5. 5. 10000.
EN
```

B.4 Rhombic

Listing B.4: An example of a Rhombic.(appendix2/Rhombic.nec)

```
CM NEC Input File for Rhombic
CM RP  0 31   73 1001  0.00E+00  0.00E+00  3.00E+00  5.00E+00  ...
   0.00E+00  0.00E+00
CE
GW  1 20   0.00000   0.00000  10.00000  17.30000  10.00000  ...
   10.00000   0.01000
GW  2 20   0.00000   0.00000  10.00000  17.30000 -10.00000  ...
   10.00000   0.01000
GW  3 20  17.30000  10.00000  10.00000  34.60000   0.00000  ...
   10.00000   0.01000
GW  4 20  17.30000 -10.00000  10.00000  34.60000   0.00000  ...
   10.00000   0.01000
GE  1
GN  1  0    0    0  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E...
   +00  0.00E+00
```

```
FR  0  1    0    0  3.00E+01  0.00E+00  0.00E+00  0.00E+00  0.00E...
   +00  0.00E+00
EX  0  1    1    0  1.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E...
   +00  0.00E+00
EX  0  2    1    0 -1.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E...
   +00  0.00E+00
LD  0  3   20    0  2.90E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
   +00  0.00E+00
LD  0  4   20    0  2.90E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
   +00  0.00E+00
RP 0 72 72 1000 -90 0 2.5 5
EN
```

B.5 Helix

Listing B.5: An example of a Helix.(appendix2/helix.nec)

```
CM Helical Antenna, by K6STI
CM Converted with 4nec2 on 22-apr-02
CM (model contains geometry violations...)
CE
SY D = .125
GW      1       1       4.35    0.00    0.00    4.35    0.00    ...
   0.50    D
GW      2       3       4.35    0.00    0.50    4.14    1.35    ...
   0.67    D
GW      3       3       4.14    1.35    0.67    3.52    2.56    ...
   0.83    D
GW      4       3       3.52    2.56    0.83    2.56    3.52    ...
   1.00    D
GW      5       3       2.56    3.52    1.00    1.35    4.14    ...
   1.17    D
GW      6       3       1.35    4.14    1.17    -0.00   4.35    ...
   1.33    D
GW      7       3       -0.00   4.35    1.33    -1.35   4.14    ...
   1.50    D
GW      8       3       -1.35   4.14    1.50    -2.56   3.52    ...
   1.67    D
GW      9       3       -2.56   3.52    1.67    -3.52   2.56    ...
   1.83    D
GW      10      3       -3.52   2.56    1.83    -4.14   1.35    ...
   2.00    D
GW      11      3       -4.14   1.35    2.00    -4.35   -0.00   ...
   2.17    D
GW      12      3       -4.35   -0.00   2.17    -4.14   -1.35   ...
   2.33    D
GW      13      3       -4.14   -1.35   2.33    -3.52   -2.56   ...
   2.50    D
GW      14      3       -3.52   -2.56   2.50    -2.56   -3.52   ...
   2.67    D
GW      15      3       -2.56   -3.52   2.67    -1.35   -4.14   ...
   2.83    D
```

```
GW      16      3       -1.35   -4.14   2.83    0.00    -4.35   ...
    3.00    D
GW      17      3       0.00    -4.35   3.00    1.35    -4.14   ...
    3.17    D
GW      18      3       1.35    -4.14   3.17    2.56    -3.52   ...
    3.33    D
GW      19      3       2.56    -3.52   3.33    3.52    -2.56   ...
    3.50    D
GW      20      3       3.52    -2.56   3.50    4.14    -1.35   ...
    3.67    D
GW      21      3       4.14    -1.35   3.67    4.35    0.00    ...
    3.83    D
GW      22      3       4.35    0.00    3.83    4.14    1.35    ...
    4.00    D
GW      23      3       4.14    1.35    4.00    3.52    2.56    ...
    4.16    D
GW      24      3       3.52    2.56    4.16    2.56    3.52    ...
    4.33    D
GW      25      3       2.56    3.52    4.33    1.35    4.14    ...
    4.50    D
GW      26      3       1.35    4.14    4.50    -0.00   4.35    ...
    4.66    D
GW      27      3       -0.00   4.35    4.66    -1.35   4.14    ...
    4.83    D
GW      28      3       -1.35   4.14    4.83    -2.56   3.52    ...
    5.00    D
GW      29      3       -2.56   3.52    5.00    -3.52   2.56    ...
    5.16    D
GW      30      3       -3.52   2.56    5.16    -4.14   1.35    ...
    5.33    D
GW      31      3       -4.14   1.35    5.33    -4.35   -0.00   ...
    5.50    D
GW      32      3       -4.35   -0.00   5.50    -4.14   -1.35   ...
    5.66    D
GW      33      3       -4.14   -1.35   5.66    -3.52   -2.56   ...
    5.83    D
GW      34      3       -3.52   -2.56   5.83    -2.56   -3.52   ...
    6.00    D
GW      35      3       -2.56   -3.52   6.00    -1.35   -4.14   ...
    6.16    D
GW      36      3       -1.35   -4.14   6.16    0.00    -4.35   ...
    6.33    D
GW      37      3       0.00    -4.35   6.33    1.35    -4.14   ...
    6.50    D
GW      38      3       1.35    -4.14   6.50    2.56    -3.52   ...
    6.66    D
GW      39      3       2.56    -3.52   6.66    3.52    -2.56   ...
    6.83    D
GW      40      3       3.52    -2.56   6.83    4.14    -1.35   ...
    7.00    D
GW      41      3       4.14    -1.35   7.00    4.35    0.00    ...
    7.16    D
```

```
GW      42      3       4.35    0.00    7.16    4.14    1.35    ...
    7.33    D
GW      43      3       4.14    1.35    7.33    3.52    2.56    ...
    7.50    D
GW      44      3       3.52    2.56    7.50    2.56    3.52    ...
    7.66    D
GW      45      3       2.56    3.52    7.66    1.35    4.14    ...
    7.83    D
GW      46      3       1.35    4.14    7.83    -0.00   4.35    ...
    8.00    D
GW      47      3       -0.00   4.35    8.00    -1.35   4.14    ...
    8.16    D
GW      48      3       -1.35   4.14    8.16    -2.56   3.52    ...
    8.33    D
GW      49      3       -2.56   3.52    8.33    -3.52   2.56    ...
    8.50    D
GW      50      3       -3.52   2.56    8.50    -4.14   1.35    ...
    8.66    D
GW      51      3       -4.14   1.35    8.66    -4.35   -0.00   ...
    8.83    D
GW      52      3       -4.35   -0.00   8.83    -4.14   -1.35   ...
    9.00    D
GW      53      3       -4.14   -1.35   9.00    -3.52   -2.56   ...
    9.16    D
GW      54      3       -3.52   -2.56   9.16    -2.56   -3.52   ...
    9.33    D
GW      55      3       -2.56   -3.52   9.33    -1.35   -4.14   ...
    9.50    D
GW      56      3       -1.35   -4.14   9.50    0.00    -4.35   ...
    9.66    D
GW      57      3       0.00    -4.35   9.66    1.35    -4.14   ...
    9.83    D
GW      58      3       1.35    -4.14   9.83    2.56    -3.52   ...
    10.00   D
GW      59      3       2.56    -3.52   10.00   3.52    -2.56   ...
    10.16   D
GW      60      3       3.52    -2.56   10.16   4.14    -1.35   ...
    10.33   D
GW      61      3       4.14    -1.35   10.33   4.35    0.00    ...
    10.49   D
GW      62      3       4.35    0.00    10.49   4.14    1.35    ...
    10.66   D
GW      63      3       4.14    1.35    10.66   3.52    2.56    ...
    10.83   D
GW      64      3       3.52    2.56    10.83   2.56    3.52    ...
    10.99   D
GW      65      3       2.56    3.52    10.99   1.35    4.14    ...
    11.16   D
GW      66      3       1.35    4.14    11.16   -0.00   4.35    ...
    11.33   D
GW      67      3       -0.00   4.35    11.33   -1.35   4.14    ...
    11.49   D
```

```
GW       68       3        -1.35    4.14     11.49    -2.56    3.52     ...
    11.66    D
GW       69       3        -2.56    3.52     11.66    -3.52    2.56     ...
    11.83    D
GW       70       3        -3.52    2.56     11.83    -4.14    1.35     ...
    11.99    D
GW       71       3        -4.14    1.35     11.99    -4.35    -0.00    ...
    12.16    D
GW       72       3        -4.35    -0.00    12.16    -4.14    -1.35    ...
    12.33    D
GW       73       3        -4.14    -1.35    12.33    -3.52    -2.56    ...
    12.49    D
GW       74       3        -3.52    -2.56    12.49    -2.56    -3.52    ...
    12.66    D
GW       75       3        -2.56    -3.52    12.66    -1.35    -4.14    ...
    12.83    D
GW       76       3        -1.35    -4.14    12.83    0.00     -4.35    ...
    12.99    D
GW       77       3        0.00     -4.35    12.99    1.35     -4.14    ...
    13.16    D
GW       78       3        1.35     -4.14    13.16    2.56     -3.52    ...
    13.33    D
GW       79       3        2.56     -3.52    13.33    3.52     -2.56    ...
    13.49    D
GW       80       3        3.52     -2.56    13.49    4.14     -1.35    ...
    13.66    D
GW       81       3        4.14     -1.35    13.66    4.35     0.00     ...
    13.83    D
GW       82       3        4.35     0.00     13.83    4.14     1.35     ...
    13.99    D
GW       83       3        4.14     1.35     13.99    3.52     2.56     ...
    14.16    D
GW       84       3        3.52     2.56     14.16    2.56     3.52     ...
    14.33    D
GW       85       3        2.56     3.52     14.33    1.35     4.14     ...
    14.49    D
GW       86       3        1.35     4.14     14.49    -0.00    4.35     ...
    14.66    D
GW       87       3        -0.00    4.35     14.66    -1.35    4.14     ...
    14.83    D
GW       88       3        -1.35    4.14     14.83    -2.56    3.52     ...
    14.99    D
GW       89       3        -2.56    3.52     14.99    -3.52    2.56     ...
    15.16    D
GW       90       3        -3.52    2.56     15.16    -4.14    1.35     ...
    15.33    D
GW       91       3        -4.14    1.35     15.33    -4.35    -0.00    ...
    15.49    D
GW       92       3        -4.35    -0.00    15.49    -4.14    -1.35    ...
    15.66    D
GW       93       3        -4.14    -1.35    15.66    -3.52    -2.56    ...
    15.83    D
```

```
GW       94      3       -3.52   -2.56   15.83   -2.56   -3.52   ...
   15.99   D
GW       95      3       -2.56   -3.52   15.99   -1.35   -4.14   ...
   16.16   D
GW       96      3       -1.35   -4.14   16.16   0.00    -4.35   ...
   16.33   D
GW       97      3       0.00    -4.35   16.33   1.35    -4.14   ...
   16.49   D
GW       98      3       1.35    -4.14   16.49   2.56    -3.52   ...
   16.66   D
GW       99      3       2.56    -3.52   16.66   3.52    -2.56   ...
   16.82   D
GW       100     3       3.52    -2.56   16.82   4.14    -1.35   ...
   16.99   D
GW       101     3       4.14    -1.35   16.99   4.35    0.00    ...
   17.16   D
GW       102     3       4.35    0.00    17.16   4.14    1.35    ...
   17.32   D
GW       103     3       4.14    1.35    17.32   3.52    2.56    ...
   17.49   D
GW       104     3       3.52    2.56    17.49   2.56    3.52    ...
   17.66   D
GW       105     3       2.56    3.52    17.66   1.35    4.14    ...
   17.82   D
GW       106     3       1.35    4.14    17.82   -0.00   4.35    ...
   17.99   D
GW       107     3       -0.00   4.35    17.99   -1.35   4.14    ...
   18.16   D
GW       108     3       -1.35   4.14    18.16   -2.56   3.52    ...
   18.32   D
GW       109     3       -2.56   3.52    18.32   -3.52   2.56    ...
   18.49   D
GW       110     3       -3.52   2.56    18.49   -4.14   1.35    ...
   18.66   D
GW       111     3       -4.14   1.35    18.66   -4.35   -0.00   ...
   18.82   D
GW       112     3       -4.35   -0.00   18.82   -4.14   -1.35   ...
   18.99   D
GW       113     3       -4.14   -1.35   18.99   -3.52   -2.56   ...
   19.16   D
GW       114     3       -3.52   -2.56   19.16   -2.56   -3.52   ...
   19.32   D
GW       115     3       -2.56   -3.52   19.32   -1.35   -4.14   ...
   19.49   D
GW       116     3       -1.35   -4.14   19.49   0.00    -4.35   ...
   19.66   D
GW       117     3       0.00    -4.35   19.66   1.35    -4.14   ...
   19.82   D
GW       118     3       1.35    -4.14   19.82   2.56    -3.52   ...
   19.99   D
GW       119     3       2.56    -3.52   19.99   3.52    -2.56   ...
   20.16   D
```

```
GW       120      3        3.52     -2.56    20.16    4.14     -1.35    ...
    20.32    D
GW       121      3        4.14     -1.35    20.32    4.35     0.00     ...
    20.49    D
GW       122      3        4.35     0.00     20.49    4.14     1.35     ...
    20.66    D
GW       123      3        4.14     1.35     20.66    3.52     2.56     ...
    20.82    D
GW       124      3        3.52     2.56     20.82    2.56     3.52     ...
    20.99    D
GW       125      3        2.56     3.52     20.99    1.35     4.14     ...
    21.16    D
GW       126      3        1.35     4.14     21.16    -0.00    4.35     ...
    21.32    D
GW       127      3        -0.00    4.35     21.32    -1.35    4.14     ...
    21.49    D
GW       128      3        -1.35    4.14     21.49    -2.56    3.52     ...
    21.66    D
GW       129      3        -2.56    3.52     21.66    -3.52    2.56     ...
    21.82    D
GW       130      3        -3.52    2.56     21.82    -4.14    1.35     ...
    21.99    D
GW       131      3        -4.14    1.35     21.99    -4.35    -0.00    ...
    22.16    D
GW       132      3        -4.35    -0.00    22.16    -4.14    -1.35    ...
    22.32    D
GW       133      3        -4.14    -1.35    22.32    -3.52    -2.56    ...
    22.49    D
GW       134      3        -3.52    -2.56    22.49    -2.56    -3.52    ...
    22.66    D
GW       135      3        -2.56    -3.52    22.66    -1.35    -4.14    ...
    22.82    D
GW       136      3        -1.35    -4.14    22.82    0.00     -4.35    ...
    22.99    D
GW       137      3        0.00     -4.35    22.99    1.35     -4.14    ...
    23.15    D
GW       138      3        1.35     -4.14    23.15    2.56     -3.52    ...
    23.32    D
GW       139      3        2.56     -3.52    23.32    3.52     -2.56    ...
    23.49    D
GW       140      3        3.52     -2.56    23.49    4.14     -1.35    ...
    23.65    D
GW       141      3        4.14     -1.35    23.65    4.35     0.00     ...
    23.82    D
GW       142      3        4.35     0.00     23.82    4.14     1.35     ...
    23.99    D
GW       143      3        4.14     1.35     23.99    3.52     2.56     ...
    24.15    D
GW       144      3        3.52     2.56     24.15    2.56     3.52     ...
    24.32    D
GW       145      3        2.56     3.52     24.32    1.35     4.14     ...
    24.49    D
```

```
GW      146     3       1.35    4.14    24.49   -0.00   4.35    ...
    24.65   D
GW      147     3       -0.00   4.35    24.65   -1.35   4.14    ...
    24.82   D
GW      148     3       -1.35   4.14    24.82   -2.56   3.52    ...
    24.99   D
GW      149     3       -2.56   3.52    24.99   -3.52   2.56    ...
    25.15   D
GW      150     3       -3.52   2.56    25.15   -4.14   1.35    ...
    25.32   D
GW      151     3       -4.14   1.35    25.32   -4.35   -0.00   ...
    25.49   D
GW      152     3       -4.35   -0.00   25.49   -4.14   -1.35   ...
    25.65   D
GW      153     3       -4.14   -1.35   25.65   -3.52   -2.56   ...
    25.82   D
GW      154     3       -3.52   -2.56   25.82   -2.56   -3.52   ...
    25.99   D
GW      155     3       -2.56   -3.52   25.99   -1.35   -4.14   ...
    26.15   D
GW      156     3       -1.35   -4.14   26.15   0.00    -4.35   ...
    26.32   D
GW      157     3       0.00    -4.35   26.32   1.35    -4.14   ...
    26.49   D
GW      158     3       1.35    -4.14   26.49   2.56    -3.52   ...
    26.65   D
GW      159     3       2.56    -3.52   26.65   3.52    -2.56   ...
    26.82   D
GW      160     3       3.52    -2.56   26.82   4.14    -1.35   ...
    26.99   D
GW      161     3       4.14    -1.35   26.99   4.35    0.00    ...
    27.15   D
GW      162     3       4.35    0.00    27.15   4.14    1.35    ...
    27.32   D
GW      163     3       4.14    1.35    27.32   3.52    2.56    ...
    27.49   D
GW      164     3       3.52    2.56    27.49   2.56    3.52    ...
    27.65   D
GW      165     3       2.56    3.52    27.65   1.35    4.14    ...
    27.82   D
GW      166     3       1.35    4.14    27.82   -0.00   4.35    ...
    27.99   D
GW      167     3       -0.00   4.35    27.99   -1.35   4.14    ...
    28.15   D
GW      168     3       -1.35   4.14    28.15   -2.56   3.52    ...
    28.32   D
GW      169     3       -2.56   3.52    28.32   -3.52   2.56    ...
    28.49   D
GW      170     3       -3.52   2.56    28.49   -4.14   1.35    ...
    28.65   D
GW      171     3       -4.14   1.35    28.65   -4.35   -0.00   ...
    28.82   D
```

```
GW     172     3       -4.35   -0.00   28.82   -4.14   -1.35   ...
   28.99   D
GW     173     3       -4.14   -1.35   28.99   -3.52   -2.56   ...
   29.15   D
GW     174     3       -3.52   -2.56   29.15   -2.56   -3.52   ...
   29.32   D
GW     175     3       -2.56   -3.52   29.32   -1.35   -4.14   ...
   29.48   D
GW     176     3       -1.35   -4.14   29.48   0.00    -4.35   ...
   29.65   D
GW     177     3       0.00    -4.35   29.65   1.35    -4.14   ...
   29.82   D
GW     178     3       1.35    -4.14   29.82   2.56    -3.52   ...
   29.98   D
GW     179     3       2.56    -3.52   29.98   3.52    -2.56   ...
   30.15   D
GW     180     3       3.52    -2.56   30.15   4.14    -1.35   ...
   30.32   D
GW     181     3       4.14    -1.35   30.32   4.35    0.00    ...
   30.48   D
GW     182     3       4.35    0.00    30.48   4.14    1.35    ...
   30.65   D
GW     183     3       4.14    1.35    30.65   3.52    2.56    ...
   30.82   D
GW     184     3       3.52    2.56    30.82   2.56    3.52    ...
   30.98   D
GW     185     3       2.56    3.52    30.98   1.35    4.14    ...
   31.15   D
GW     186     3       1.35    4.14    31.15   -0.00   4.35    ...
   31.32   D
GW     187     3       -0.00   4.35    31.32   -1.35   4.14    ...
   31.48   D
GW     188     3       -1.35   4.14    31.48   -2.56   3.52    ...
   31.65   D
GW     189     3       -2.56   3.52    31.65   -3.52   2.56    ...
   31.82   D
GW     190     3       -3.52   2.56    31.82   -4.14   1.35    ...
   31.98   D
GW     191     3       -4.14   1.35    31.98   -4.35   -0.00   ...
   32.15   D
GW     192     3       -4.35   -0.00   32.15   -4.14   -1.35   ...
   32.32   D
GW     193     3       -4.14   -1.35   32.32   -3.52   -2.56   ...
   32.48   D
GW     194     3       -3.52   -2.56   32.48   -2.56   -3.52   ...
   32.65   D
GW     195     3       -2.56   -3.52   32.65   -1.35   -4.14   ...
   32.82   D
GW     196     3       -1.35   -4.14   32.82   0.00    -4.35   ...
   32.98   D
GW     197     3       0.00    -4.35   32.98   1.35    -4.14   ...
   33.15   D
```

```
GW      198     3       1.35    -4.14   33.15   2.56    -3.52   ...
   33.32   D
GW      199     3       2.56    -3.52   33.32   3.52    -2.56   ...
   33.48   D
GW      200     3       3.52    -2.56   33.48   4.14    -1.35   ...
   33.65   D
GW      201     3       4.14    -1.35   33.65   4.35    0.00    ...
   33.82   D
GS      0       0       in
GE      1
EX      0       1       1       00      1.0     0.0
'
GN      0       0       0       0       13      .005
FR      0       1       0       0        435
EN
'This 10-turn, monofilar, axial-mode helix with 7-degree pitch ...
   yields right-
'circular polarization.  Each turn has 20 segments.  The pitch ...
   angle was varied
'for maximum gain.
```

B.6 Disc Cone

Listing B.6: An example of a fat Disc Cone.(appendix2/discone.nec)

```
CM Biconical antenna
CM Cone angle 30 deg.
CE
GW  1    1     0.0000   -0.0250    0.0000    0.0000    0.0250    ...
   0.0000 .00300000
GW  0   20     0.0000    0.0250    0.0000    0.3000    0.5446    ...
   0.0000 .00300000
GW  0   20     0.0000    0.0250    0.0000   -0.3000    0.5446    ...
   0.0000 .00300000
GW  0   20     0.0000    0.0250    0.0000    0.0000    0.5446   ...
   -0.3000 .00300000
GW  0   20     0.0000    0.0250    0.0000    0.0000    0.5446    ...
   0.3000 .00300000
GW  0   20     0.0000    0.0250    0.0000    0.2121    0.5446    ...
   0.2121 .00300000
GW  0   20     0.0000    0.0250    0.0000   -0.2121    0.5446   ...
   -0.2121 .00300000
GW  0   20     0.0000    0.0250    0.0000    0.2121    0.5446   ...
   -0.2121 .00300000
GW  9   20     0.0000    0.0250    0.0000   -0.2121    0.5446    ...
   0.2121 .00300000
GW 10   20    -0.3000   -0.5446    0.0000    0.0000   -0.0250    ...
   0.0000 .00300000
GW 11   20     0.3000   -0.5446    0.0000    0.0000   -0.0250    ...
   0.0000 .00300000
GW 12   20     0.0000   -0.5446    0.3000    0.0000   -0.0250    ...
   0.0000 .00300000
```

```
GW 13   20    0.0000   -0.5446   -0.3000    0.0000   -0.0250    ...
    0.0000 .00300000
GW 14   20   -0.2121   -0.5446   -0.2121    0.0000   -0.0250    ...
    0.0000 .00300000
GW 15   20    0.2121   -0.5446    0.2121    0.0000   -0.0250    ...
    0.0000 .00300000
GW 16   20   -0.2121   -0.5446    0.2121    0.0000   -0.0250    ...
    0.0000 .00300000
GW 17   20    0.2121   -0.5446   -0.2121    0.0000   -0.0250    ...
    0.0000 .00300000
GE  0
EX      0       1       1       00      1.0000  0.0000
FR      0       0       0       0       50
EN
```

B.7 Yagi-Uda

Listing B.7: An example of a Yagi-Uda.(appendix2/Yagi16.nec)

```
CM NEC Input File of a 16 element Yagi
cm RP  0 31   73 1001  0.00E+00  0.00E+00  3.00E+00  5.00E+00  ...
    1.00E+04  0.00E+00
CE
GW 15  7   0.00000  -0.34000   0.00000   0.00000   0.34000   ...
    0.00000   0.00250
GW 16  7   0.27300  -0.31750   0.00000   0.27300   0.31750   ...
    0.00000   0.00250
GW  1  7   0.69300  -0.30500   0.00000   0.69300   0.30500   ...
    0.00000   0.00250
GW  2  7   1.11300  -0.30500   0.00000   1.11300   0.30500   ...
    0.00000   0.00250
GW  3  7   1.53300  -0.30500   0.00000   1.53300   0.30500   ...
    0.00000   0.00250
GW  4  7   1.95300  -0.30500   0.00000   1.95300   0.30500   ...
    0.00000   0.00250
GW  5  7   2.37300  -0.30500   0.00000   2.37300   0.30500   ...
    0.00000   0.00250
GW  6  7   2.79300  -0.30500   0.00000   2.79300   0.30500   ...
    0.00000   0.00250
GW  7  7   3.21300  -0.30500   0.00000   3.21300   0.30500   ...
    0.00000   0.00250
GW  8  7   3.63300  -0.30500   0.00000   3.63300   0.30500   ...
    0.00000   0.00250
GW  9  7   4.05300  -0.30500   0.00000   4.05300   0.30500   ...
    0.00000   0.00250
GW 10  7   4.47300  -0.30500   0.00000   4.47300   0.30500   ...
    0.00000   0.00250
GW 11  7   4.89300  -0.30500   0.00000   4.89300   0.30500   ...
    0.00000   0.00250
GW 12  7   5.31300  -0.30500   0.00000   5.31300   0.30500   ...
    0.00000   0.00250
GW 13  7   5.73300  -0.30500   0.00000   5.73300   0.30500   ...
    0.00000   0.00250
```

```
GE  0
FR  0  1    0    0  2.20E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
    +00  0.00E+00
EX  0 16    4    0  1.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E...
    +00  0.00E+00
RP 0 73 37 1000 -90 0 2.5 5
EN
```

B.8 LPDA I

Listing B.8: First example of a LPDA.(appendix2/Logper.nec)

```
CM NEC Input File for log-periodic
CM PT control card supresses printing of element currents
CM TL control card specs transmission line in terms of Z,length,...
    and shunt Y
CM <- RP  0 37   37 1001  0.00E+00  0.00E+00  5.00E+00  1.00E+01  ...
    0.00E+00  0.00E+00
CM <- PT -1
CE
GW  3  7  -9.66700  -2.14200   0.00000  -9.66700   2.14200   ...
    0.00000   0.00429
GW  4  7 -11.10700  -2.46300   0.00000 -11.10700   2.46300   ...
    0.00000   0.00493
GW  5  7 -12.76800  -2.83200   0.00000 -12.76800   2.83200   ...
    0.00000   0.00566
GW  6  9 -14.67500  -3.25500   0.00000 -14.67500   3.25500   ...
    0.00000   0.00651
GW  7  9 -16.86500  -3.74100   0.00000 -16.86500   3.74100   ...
    0.00000   0.00750
GW  8  9 -19.38300  -4.29900   0.00000 -19.38300   4.29900   ...
    0.00000   0.00860
GW  9 11 -22.27700  -4.94400   0.00000 -22.27700   4.94400   ...
    0.00000   0.00988
GW 10 11 -25.60300  -5.68200   0.00000 -25.60300   5.68200   ...
    0.00000   0.01136
GW 11 11 -29.42500  -6.53100   0.00000 -29.42500   6.53100   ...
    0.00000   0.01305
GE  0
TL  3  4    4    4 -4.50E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
    +00  0.00E+00
TL  4  4    5    4 -4.50E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
    +00  0.00E+00
TL  5  4    6    5 -4.50E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
    +00  0.00E+00
TL  6  5    7    5 -4.50E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
    +00  0.00E+00
TL  7  5    8    5 -4.50E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
    +00  0.00E+00
TL  8  5    9    6 -4.50E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
    +00  0.00E+00
TL  9  6   10    6 -4.50E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
    +00  0.00E+00
```

```
TL 10  6   11    6 -4.50E+02  0.00E+00  0.00E+00  0.00E+00  0.00E...
   +00  -2.20E-03
EX  0  3    4    0  1.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E...
   +00  0.00E+00
FR  0  1    0    0  1.20E+01  4.00E+00  0.00E+00  0.00E+00  0.00E...
   +00  0.00E+00
RP 0 37 37 1000 -90 0 5 10
EN
```

B.9 LPDA II

Listing B.9: Second example of a LPDA.(appendix2/lpda.nec)

```
CM NEC Input File LPDA 2412..2472 MHz, Pow 20020609  |
CM Log periodic dipole array feed                    |
CM   + 7 elements                                    |
CM   + 10.7 dBi gain, f/b ratio 27 dB                |
CM   + 50 deg vertical, 70 horizontal 3 dB beamwidth |
CM   + SWR < 1.3                                     |
CM All data in wavelengths. Scaled to meters with GS |
CE
SY  R= .006
SY L1= .166 ,L2= .176 ,L3= .187 ,L4= .199 ,L5= .212 ,L6= .226 ,L7=...
    .240
SY D1= .000 ,D2= .125 ,D3= .133 ,D4= .141 ,D5= .151 ,D6= .160 ,D7=...
    .170
SY X1=D1, X2=X1-D2, X3=X2-D3, X4=X3-D4, X5=X4-D5, X6=X5-D6, X7=X6-...
   D7
GW 1 21 X1 0. L1 X1 0. -L1 R
GW 2 21 X2 0. L2 X2 0. -L2 R
GW 3 21 X3 0. L3 X3 0. -L3 R
GW 4 21 X4 0. L4 X4 0. -L4 R
GW 5 21 X5 0. L5 X5 0. -L5 R
GW 6 21 X6 0. L6 X6 0. -L6 R
GW 7 21 X7 0. L7 X7 0. -L7 R
GS 0 0 300.0/2442.0
GE 0
TL 1 11 2 11 -50. 0. 0. 0. 0. 0.
TL 2 11 3 11 -50. 0. 0. 0. 0. 0.
TL 3 11 4 11 -50. 0. 0. 0. 0. 0.
TL 4 11 5 11 -50. 0. 0. 0. 0. 0.
TL 5 11 6 11 -50. 0. 0. 0. 0. 0.
TL 6 11 7 11 -50. 0. 0. 0. 0. 0.
FR 0 1 0 0 2442. 0
EX 0 1 11 0 1.  0
RP 0 73  73 1001 -90. 90. 5. 5. 10000.
EN
```

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AFRL/SNRW
POC: Michael Murray
2241 Avionics Circle, Bldg 620 Rm 3AK51
Wright-Patterson AFB, OH 45433-7321
937-255-5579 x4249
Michael.Murray@wpafb.af.mil

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14. ABSTRACT A Genetic Algorithm (GA) is used in accord with NEC4 to create and optimize typical wire antenna designs including single elements and arrays, the result being antennas with impressive characteristics. Design parameters for the antenna are defined and encoded into a chromosome composed of a series of numbers. The cost function associated is created and used by the GA to evaluate the performance of a population of antenna designs. The most successful designs of each generation are kept and altered through crossover and mutation. Convergence upon a *best* design is attained. The Yagi-Uda and the Log Periodic Dipole Array (LPDA) antenna are the focus for this study. The objectives for each are to maximize the main power gain while minimizing the Voltage Standing Wave Ratio (VSWR) and the antenna's length. The Yagi-Uda improves by as much as 40 dB in the main lobe compared to previous studies. LPDA improvements are nominal power gain while truncating original allowance in the length by more than half along with nominal VSWR values that were close to ideal value of one. This methodology is very robust and is improved upon in this research all while using a novel approach with an optimization program platform called iSIGHT.

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